NASA TECHNICAL TRANSLATION NASA TT F-17,129

PRELIMINARY SCIENTIFIC RESULTS OBTAINED DURING THE FLIGHT OF THE VENERA-9 AND VENERA-10 AUTOMATIC INTERPLANETARY STATIONS

V. I. Moroz and N. N. Krupenio

(NASA-TT-F-17129) PRELIMINARY SCIENTIFIC RESULTS OBTAINED DURING THE FLIGHT OF THE VENERA 9 AND VENERA 10 AUTOMATIC INTERPLANETARY STATIONS (Kanner (Leo) Associates) 58 p HC $4.50 CSCL 03B G3/91
N76-33133
Unclas
48730

Translation of "Predvaritel'nyye Nauchnyye Rezul'taty, Poluchennyye pri Polete Avtomaticheskikh Mezhplanetnykh Stantsiy "Venera-9" i "Venera-10"," Academy of Sciences USSR, Institute of Space Research, Moscow, Report Pr-278, 1976, pp. 1-60

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 AUGUST 1976

STANDARD TITLE PAGE

1. Report No. NASA TT F-17,129	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle PRELIMINARY SCIENTIFIC RESULTS OBTAINED DURING THE FLIGHT OF THE VENERA 9 AND VENERA 10 AUTOMATIC INTERPLANETARY STATIONS		5. Report Date August 1976
		6. Performing Organization Code
7. Author(s) Various authors, as indicated in table of contents		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates Redwood City, California 94063		11. Contract or Grant No. NASw 2790
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes Translation of "Predvaritel'nyye Nauchnyye Rezul'taty, Poluchennyye pri Polete Avtomaticheskikh Mezhplanetnykh Stantsiy "Venera-9" i "Venera-10"," Academy of Sciences USSR, Institute of Space Research, Moscow, Report Pr-278, 1976, pp. 1-60

16. Abstract

Brief reports are given on the exploration of Venusian atmosphere and surface terrain by Venera 9 and Venera 10 interplanetary automatic stations reaching Venus in October 1975. Two descent modules soft-landed on the surface of the planet and two artificial satellites went into planetary orbits. Meteorological characteristics, optical properties of Venusian cloud covers, and surficial physical and geomorphological properties were investigated. Also explored was the near-planetary magnetic field, the night and day ionospheres, and cloud particle size at different altitudes above the planet.

17. Key Words (Selected by Author(s))		18. Distribution Statement Unclassified - Unlimited	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 58	22. Price

NASA-HQ

FOREWORD

In October 1975 the Venera 9 and Venera 10 interplanetary automatic stations reached the closest approach to the planet Venus. Two descent modules made a soft landing on the surface of the planet, and for the first time two artificial satellites went into orbits around the planet. For the first time photo-television panoramas of the landing site were obtained and the soil density of the surface was determined. The complex of instrumentation on the descent modules was used to measure the meteorological characteristics, optical properties of clouds, and to study physical and geologomorphological characteristics of the surface. A multilayer cloud cover structure was found and particle sizes were estimated at different altitudes above the surface. Investigation of the cloud layer and the atmosphere was conducted simultaneously on the orbiting modules with optical and radiophysical devices. Onboard the artificial satellites a bistatic radar scan of the planet was made for the first time, yielding data on surface terrain. The instrumentation aboard the artificial Venus satellites yielded much new information on the magnetic field near the planet, on the interaction between solar wind and planet, on the night and day ionospheres, and information on the upper planetary surface.

This collection gives brief reports of the preliminary findings from processing the data of the scientific experiments. Most of the reports are summaries of articles presented in the journal Kosmicheskiye Issledovaniya. These articles will be published in a special theme issue at the close of 1976.

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1. SURFACE STUDIES /4*

PHOTOGRAMMETRIC PROCESSING OF MATERIALS OF A TELEVISION SURVEY OF THE SURFACE OF VENUS

B. V. Nepoklonov, Yu. S. Tyuflin, and Ye. Aleksashin

On 22 and 25 October 1975, a television survey was made of the Venusian surface from the descent modules (DM) of the Venera 9 and Venera 10 automatic stations. The survey was done with television optico-mechanical panorama type cameras.

The television panoramas obtained on Earth after the signals were relayed with the Venera 9 and Venera 10 artificial satellites afforded the first representation of the features of the Venusian surface.

Earth interpretation of the television parameters of the Venusian surface included:

digital processing to eliminate panorama distortions (malfunction of sweep trace and pulse noise)

"insertion" of information instead of telemetry cuts from part of the panoramas obtained in the reverse sweep of the cameras

geometrical transformation of the television panoramas to convert them into panoramas with a vertical axis of panorama sweep, and

constructing topographic mosaics of the landing site of the Venera 9 and Venera 10 descent modules.

When the topographic mosaics were constructed, the planetary surface was approximated by the plane over the area photographed. Orientation of the cameras was determined relative to the normal to the approximating surface. The position of the normal in the recording camera coordinate system was found from the image of the visible horizon line on the panorama. /5

Topographic mosaics were plotted as projections of images of the television panoramas onto the approximating surface.

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*Numbers in the margin indicate pagination in the foreign text.

Interpretation of the television panoramas showed that the Venera 9 descent modules had landed at a portion of the surface that had an inclination to the gravitational vertical of 30°. All the surface recorded was occupied by rocky detritus, with rock size from several centimeters to 1-2 m.

The intervals between the rocks were covered with Venusian soil, resembling lunar regolith in structure.

The landing site of Venera 10 was level. The angle of inclination of the station to the gravitational vertical was 8°. Fairly smooth outcroppings of bedrock with traces of temperature and wind erosion could be seen at the landing site. Reworked material of the surficial layer had an albedo 10-15 times weaker than the bedrock albedo. Local irregularities were up to several centimeters in size.

TERRAIN OF TWO AREAS OF VENUS FROM BISTATIC RADAR SCAN OF THE PLANET WITH VENERA 10 ARTIFICIAL SATELLITE

M. A. Kolosov, O. I. Yakovlev, A. G. Pavel'yev,
S. L. Azarkh, A. I. Kucheryavenkov, S. S. Matyugov,
V. I. Kayevitser, V. I. Rogal'skiy, V. S. Polyakov,
and I. E. Kalashnikov

Results of an experiment on a bistatic radar scan of two areas of Venus 800 and 600 km in size are presented. The distance between the areas investigated was 400 km, and their width was about 20 km. The coordinates of the initial and terminal sections for the first part of the surface were: latitude 19.7° and - 11.6°, longitude 223.5° and 232.4°. The /6
coordinates of the initial and terminal sections for the second part of the surface were: latitude 17.5° and - 13.6°, and longitude 219.6° and 224.5° (Fig. 1).

The investigation showed that typical of the first area is a transition from level sections to a mountainous locale, upthrust about 2 km above the mean surface. At the end of the route was observed a reverse transition to sections below the mean surface level. The root-mean-square inclinations of the i-regularities in the first area varied in the range 2°-5°. The second of the regions studied had a lowland terrain. The inclinations of the irregularities in this area averaged 1.5° ± ± 0.5°.

The comparison of the areas studied on Venus with the lunar surface indicates a similarity to the first area with the hilly portions, transitional from the lunar maria to the uplands. The second region is analogous to the planes of the lunar maria.

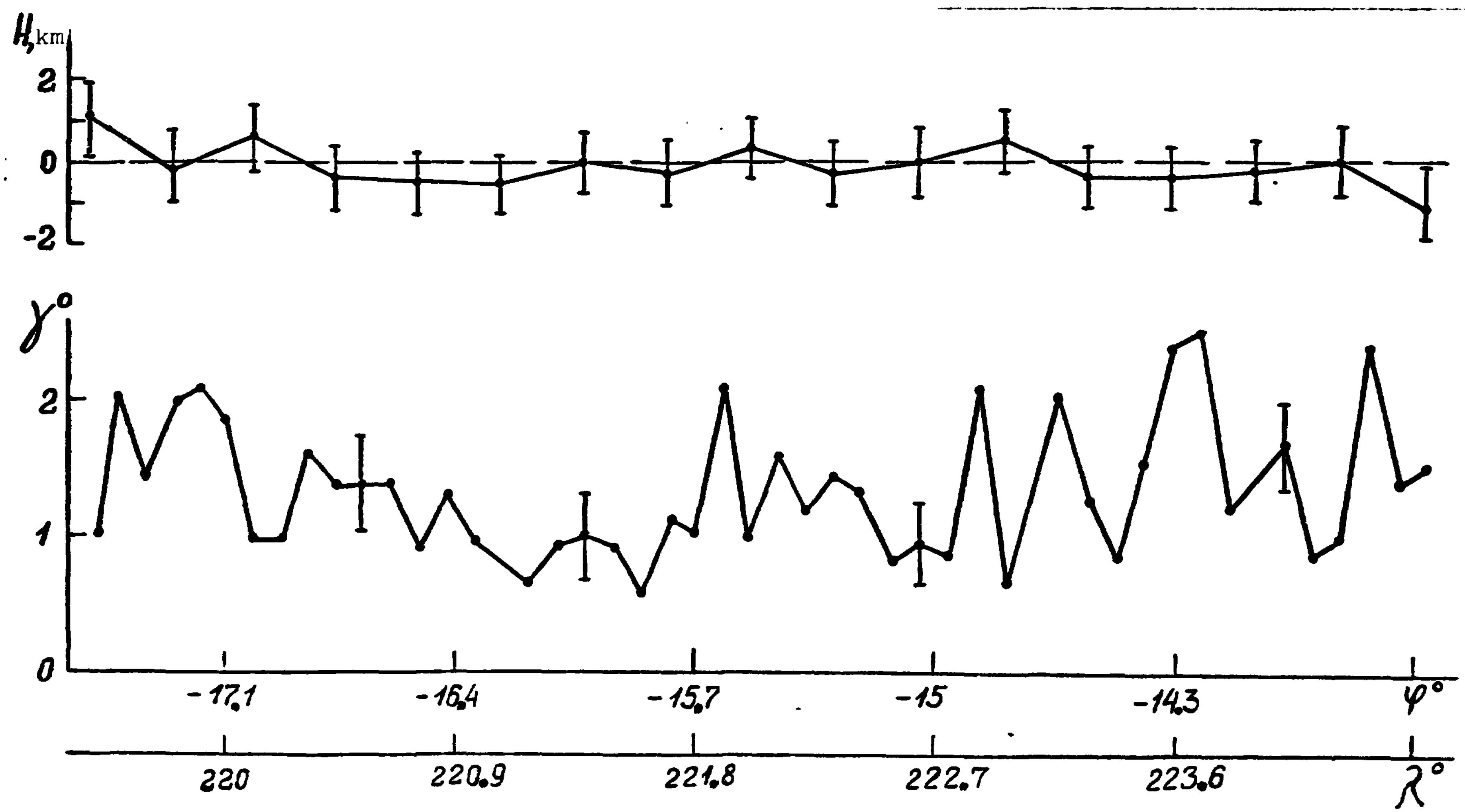

Fig. 1. Altitudes and root-mean square inclinations of irregularities of Venusian surface

MEASUREMENT OF WIND VELOCITY AT THE SURFACE OF VENUS

V. S. Avduyevskiy, S. L. Vishnevetskiy, I. A. Golov, Yu. Ya. Karneyskiy, A. D. Pavlov, V. Ya. Likhumin, M. Ya. Marov, D. A. Mel'nikov, I. N. Pomogin, N. N. Pronina, K. A. Razin, and V. G. Fokin

In experiments with the Venera 9 and Venera 10 automatic interplanetary stations [AIS], wind velocity at the planetary surface was measured for the first time. The system of measuring wind velocity (the WVM instrument) developed for these stations functioned as part of the descent modules (DM) over the terminal section of the descent and during the period of surface operation. The instrument included two cup-type anemometers installed above the deceleration flap of the DM at a height of H = 1.3 m from the base of the landing site. The /8 anemometers were alternately connected to an electronic frequency meter, whose output voltage was transmitted along one of the telemetry channels. The system was designed to measure the modulus of the wind velocity independent of its direction. The instrument had no heat-protective coating and it operated at about 500° C and at a pressure of about 100 atm after being acted on by large shock g-loads. Choice of the best anemometer layout on the DM (in conditions of rigid weight, dimensional, and functional constraints) and calibration of the instrument required a complex of aero-gas dynamic developments and investigations. The calibration dependence of the instrument's output voltage on wind velocity was obtained with reference to the effect of full-scale parameters on the Venusian surface and the geometry of the DM in conditions of a circular inflow. Gas-dynamic studies and thermal-strength tests of the isolated instrument (without the DM) were made with the reproduction of a full-scale values of the Reynolds number, density, temperature, and velocity. The error of the isolated instrument when V = 0.5-1 m/sec was in the range ± 0.2 m/sec, and the sensitivity threshold was below 0.1 m/sec. The effect of the DM on instrument performance was studied in a wind tunnel and in a meteorological proving ground. Instrument serviceability was achieved in complex conditions of alternate flow past a DM of unusual configuration at a small elevation of anemometer placement above the deceleration flap. The extent of the effect of the DM on instrument readings when two sensors were operating and when the angles of deflection of the module axis from the normal to the planetary surface was less than 10° was found with the probability of more than 0.9 in the range ± 20 percent of the measured wind velocity.

In an experiment on Venera 9, the wind velocity at the Venusian surface was measured with two sensors. The mean wind velocity during the time the station was functioning was found close to 0.5 m/sec. In an experiment on Venera 10, the mean wind velocity was $V = 1$ m/sec. The variations of this quantity /9 were small.

Thus, wind at a velocity $V = 0.5$-1 m/sec was detected at an elevation of about 1 m above the Venusian surface.

RESULTS OF GEOLOGO-MORPHOLOGICAL ANALYSIS OF SURFACE PANORAMAS

K. P. Florenskiy, A. T. Bazilevskiy, and A. A. Pronin

Analysis of television images of the Venusian surface transmitted from the descent modules of Venera 9 and Venera 10 showed that the Venera 9 descent module [DM] landing site was in a detritus of acicular rocks covering a fairly steep slope, and the Venera 10 DM had landed on a level locale with rounded outcroppings of bedrock. Signs of breakdown were visible in the rocks of the Venera 10 DM landing site, caused by surficial agents -- sand corrosion type rounding of edges and cellular weathering type pitting of rock faces. At both landing sites relatively fine-grained, porous, probably loose soil was observed between the rocks. The high degree of surface stoniness at the landing sites is in agreement with earlier radar estimates of the mean density of surficial material; this allows us to regard the landscapes of the areas studied to be typical of Venus. The general high stoniness of the Venusian surface may indicate weak intensity of breakdown and transport of surficial material and the low probability that thick strata of sedimentary rocks had formed.

DENSITY OF SURFICIAL ROCKS OF VENUS FROM DATA RECORDED ON VENERA 10 AUTOMATIC INTERPLANETARY STATION /10

Yu. A. Surkov, F. F. Kirnozov, V. K. Khristianov,
V. N. Glazov, V. F. Ivanov, and V. N. Korchuganov

Knowledge of the density of the surficial rocks of Venus is vital both for understanding the direction of geochemical processes occurring on the planet and in estimating physical-engineering parameters of planetary soil.

Before the flight of the Venera 10 spacecraft, only radar and radio-astronomical observations were the source of information on density.

Data of these methods have large scatter and are averaged for more or less significant depths; they cannot characterize the upper rock layer directly in contact with the atmosphere. Therefore a direct determination of rock density using a radiation densimeter was made on the Venera 10 descent module.

The method was based on scattering of gamma radiation by the medium analyzed. The three-probe densimeter design developed was capable of analyzing rock density under extremal climatic conditions existing on the surface of Venus (pressure to 100 atm and temperature to 500° C).

The telemetric data obtained indicate that the instrument wholly retained its parameters during the flight from Earth to Venus and functioned stably during the descent and on the planetary surface.

From the readings of the three densimeter probes, taking statistical errors into account in determining the counting /11
rates at the Venusian surface and errors associated with calibration, it was found that the density of monolithic rock is 2.8 ± 0.1 g/cm^3.

The recorded Venusian rock density evidences that outcroppings of rocky formations visible on the surface parameter are represented by fairly dense rock, only slightly modified by surficial processes. This rock density value is also in agreement with our concept of the basalt composition of the planetary core in the area of the station's landing site. The density of 2.7-2.9 g/cm^3, in terms of terrestrial analogs, indicates basalts of massive texture with low porosity. These rocks could have formed with slow cooling of basaltic lavas and only slight gas release.

From the density recorded, pertaining to the uppermost rock layer 5-7 cm thick, we may conclude that the rocks are chemically stable in the Venusian atmosphere. Evidently, they were not subject to strong mechanical weathering. The low effectiveness of these processes is indicated also by the morphological features of the surface observed in the panoramas. Thus, the results of the experiment furnish grounds for revising the earlier-held idea that intensive erosive processes occur on the Venusian surface.

INVESTIGATION OF GAMMA-RADIATION OF VENUS

Yu. A. Surkov, F. F. Kirnozov, V. N. Glazov,
and G. A. Fedoseyev

Measurements of gamma-radiation spectra in the energy range 1.0-3.0 MeV were made along the space station descent path in the Venusian atmosphere and after landing on the planetary surface, using scintillation gamma-spectrometers onboard the descent modules of Venera 9 and Venera 10. Analysis of the /12 results based on calculation measurements of different magmatic rocks of the Earth, with reference to errors caused by the effect of the dense Venusian atmosphere afforded a determination of the content of natural radioactive elements in the station landing site.

TABLE

Content of K, U, and Th in Venusian rocks

Rocks at the DM landing site	Content		
	Potassium %	Uranium 10^{-4}%	Thorium 10^{-4}%
Venera 9	0,47±0,08	0,60±0,16	3,65±0,42
Venera 10	0,30±0,16	0,46±0,26	0,70±0,34

Preliminary examination of these data showed that Venusian rocks at both planetary sites are similar in their content of natural radioactive elements to basalt type terrestrial rocks (tholeiitic and alkalic) and differ markedly from the rocks at the landing site of Venera 8 automatic interplanetary station.

Comparison with data recorded with a radiation densimeter and analysis of panoramic photographs suggested the broad distribution on the planetary surface of extrusive rocks of basic composition. The possibility of the formation of acidic rocks in some areas of the planet is not precluded, as established by Venera 8.

2. INVESTIGATION OF ATMOSPHERE AND CLOUD LAYER FROM DESCENT MODULES /13

MEASUREMENT OF ATMOSPHERIC PARAMETERS DURING DESCENT OF AUTOMATIC STATIONS TO SURFACE OF PLANET

V. S. Avduyevskiy, N. F. Borodin, V. P. Burtsev, Ya. V. Malkov, M. Ya. Marov, S. F. Morozov, M. K. Rozhdestvenskiy, R. S. Romanov, S. S. Sokolov, V. G. Fokin, Z. P. Cheremukhina, and V. I. Shkirina

By direct measurements, temperature and pressure profiles in the altitude range 0-63 km were recorded for the day side of the planet at solar elevation angles above the horizon of about 56.5° C and about 62.3° C. Higher temperatures were obtained for the day side in the 63-50 km altitude range compared to the night side (by about 30° C). The mean temperature gradient was γ_{av} = 7°/km. The temperature and pressure at the surface, in the landing sites, was P_s [s = landing site] = 85-91 kg/cm^2 and T_s = 730-740° K. Measurements of the axial g-load resulting from aerodynamic braking of the DM [descent module] were made in the 63-95 km altitude range. The measured maximum g-loads on the Venera 9 and Venera 10 descent modules were 136 $\pm$ 3 units and 167.5 $\pm$ 0.5 units, respectively.

The density profile above 63 km found by solving the system of equations of DM motion in the atmosphere, using the measured function nx = f(t), differed from the density profile for a model adopted in the calculations. The atmosphere at these altitudes was found denser and the mean density gradient was β^{av}_{str} = 0.195 km^{-1} (less than in the calculated model). The solution of the hydrostatic equation for these altitudes yielded a temperature profile with the gradient γ_{av} = 2.2° km^{-1}. At the level at which nx_{max} was traversed (H = 76 km), these parameters were /14
obtained: $\rho = 3.3 \cdot 10^{-3}$ kg$\cdot$sec$^2\cdot$m^{-4}, and T = 235° K.

ESTIMATES OF WIND VELOCITY AND TURBULENCE FROM RETRANSMISSION DOPPLER MEASUREMENTS OF DESCENT MODULES

N. M. Antsibor, R. V. Bakit'ko, A. L. Ginzburg, V. T. Guslyakov, V. V. Kerzhanovich, Yu. F. Makarov, M. Ya. Marov, Ye. P. Molotov, V. I. Rogal'skiy, M. K. Rozhdestvenskiy, V. P. Sorokin, and Yu. N. Shnygin

Measurements of the velocities of Venera 9 and Venera 10 descent modules probing the atmosphere on the side of the planet not seen from the Earth were made by the doppler retransmission method by retransmitting signals via the orbital modules of the stations. From the frequency of the signal received on Earth, the velocity was determined to a constant component associated with the drift of the frequency of the quartz master oscillator of the DM during the flight time; the random root-mean-square error of measurements was less than 10 cm/sec. When the measurements were processed, corrections were introduced for the temperature drift of the oscillator frequency.

The imprecisions in the determination of the DM descent points and the trajectories of the orbital craft, along with small zenithal distances of the orbital modules during the descent time made it harder to isolate the regular wind velocity components from the doppler measurements. To determine the constant displacement of the oscillator frequency and the deviation of the landing sites from the calculated values, use was made of measurements of the frequency of the signal received after landing. The wind velocity was found by integrating equations including differences of the measured and calculated /15
and allowing for the horizontal drift of the module caused by the wind. Estimates of atmospheric turbulence were found directly from the irregular variations of the doppler velocity.

From preliminary estimates, wind velocity at the beginning of the descent was up to 60 m/sec at altitudes above 50 km. With decrease in altitude, the wind velocity became smaller and near the surface (at the altitude of 30-40 m), its estimates were 0.8 ± 1.0 m/sec for Venera 9 and 0.6 ± 1.0 m/sec for Venera 10. The turbulent velocity fluctuations did not exceed 1.0-1.5 m/sec at all altitudes, including the cloud layer; the relatively small turbulence indicates that Venusian clouds are evidently more like stratus terrestrial clouds, than cumulus terrestrial clouds.

PRELIMINARY RESULTS OF NARROW-BAND PHOTOMETRIC PROBING OF THE VENUSIAN CLOUD LAYER IN THE 0.8-0.87 μm SPECTRAL REGION

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V. S. Zhegulev, L. V. Zasova, and Ye. A. Ustinov

On Venera 9 and Venera 10 descent modules were installed identical photometers measuring the intensity of atmosphere-scattered solar radiation arriving at 45° to the zenith, as the stations descended in the altitude range 64-34 km. The width of the radiation pattern was about 5°. Radiation was received in three narrow (about 50 Å) spectral regions, centered on the wavelengths 8700, 8200, and 8000 Å. The first of these corresponds to the CO_2 band, the second to the H_2O band, and the third to the continuous spectrum.

The intensity of scattered solar radiation in the continuous spectrum gradually decreases with descent into the planetary atmosphere. Superimposed on this monotonic decrease are significant fluctuations associated with the flocculent structure of the clouds. Absorption in the CO_2 and H_2O bands rises strongly during a descent below the 40 km level. The measurements can be correlated with this model of the structure of the scattering medium: a) the principal cloud layer with a scattering coefficient of about 1.10^{-5} cm^{-1} and a particle number concentration of about 200 cm^{-3} is above 50 km. In the 35-50 km altitude range, the scattering coefficient is two to three times smaller. The presence of a second cloud layer at the altitudes of 35-45 km is not precluded. Below 35 km there is a probable predominance of scattering in a gaseous Rayleigh atmosphere. b) Throughout the altitude range investigated, evidently there are conditions that are similar to conservative scattering $I - a \lesssim 10^{-3}$ (where a is the albedo of single scattering) with a total optical thickness of about 25; c) the cloud layer consists of individual compact formations, whose size falls in the range from several hundreds of meters to several kilometers; and d) the ratio of the volume content of H_2O/CO_2 is $\sim 10^{-3}$ in the altitude range of 25-45 km (Fig. 2).

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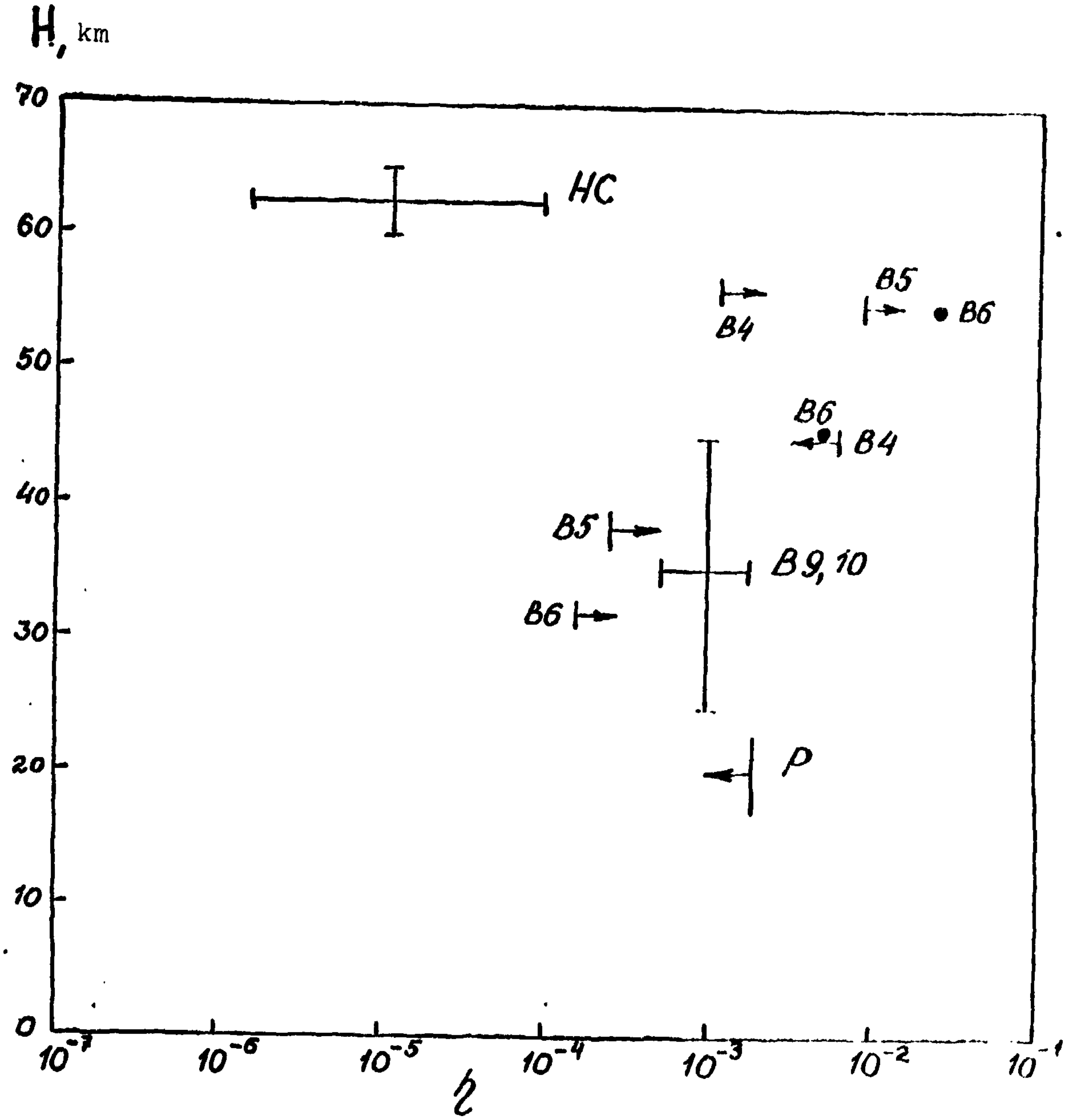

Fig. 2

Results of measuring the H_2O abundance in the Venusian atmosphere. Plotted along the X axis is η, the relative volume content of H_2O. HC stands for terrestrial spectroscopy, P -- -- radioastronomy, and B4-B10, for Soviet descent modules. The arrows indicate the upper and lower limits.

PRELIMINARY RESULTS OF INVESTIGATING ILLUMINATION CONDITIONS IN THE ATMOSPHERE AND ON THE SURFACE OF VENUS

V. S. Avduyevskiy, Yu. M. Golovin, F. S. Zavelevich, V. Ya. Likhushin, M. Ya. Marov, D. A. Mel'nikov, Ya. I. Merson, B. Ye. Moshkin, K. A. Razin, L. I. Chernoshchekov, and A. P. Ekonomov

The instruments were installed on the descent modules [DM] of Venera 9 and Venera 10. The instrument sensors had an autonomous thermal insulation system, and the electronic blocks were within the instrument bay of the DM. On both stations, the instruments sent out over all telemetry channels information on altitude of about 63 km before the communications system ceased operating, that is, about 60 min after landing.

From the experiments information was obtained concerning the distribution of the intensive solar radiation in five spectral ranges, with the maxima of spectral sensitivity as follows: 0.52 μm, 0.59 μm, 0.65 μm, 0.72 μm, and 0.96 μm.

These data relate to three geometrically distinct optical beams fixing the radiation from the upper hemisphere with a cosinusoidal radiation pattern, from the zenith, and from a direction of 23° from the nadir, with the radiation patterns within the limits of the angle $\pm$ 20°, respectively.

The data obtained on the illumination conditions and changes in these conditions with change in altitude in the atmosphere in both experiments agreed closely.

Altitude functions of the albedo defined by us as the ratio of the measurements of the incoming and outgoing fluxes were calculated, measured by the optical heads of the instruments directed downward and upward (the head with a cosinusoidal radiation pattern).

In the initial part of the curves of the altitude distribution of illumination inflection points were noted; these can be interpreted as the lower limit of the cloud layer, at the altitude of 50 km $\pm$ 2 km. /19

Below 15 km, the attenuation mechanism in all the spectral ranges studied can be attributed to Rayleigh scattering. In the altitude range 50 km < H < 15 km the presence of finely dispersed aerosol or true absorption is not precluded.

The value of the albedo for the large altitudes changed only slightly.

In direct proximity to the surface (altitude of $\sim$ 5 km) an abrupt decrease in the albedo was observed, which can be explained by the effect of the surface albedo at small altitudes.

In the experiments information was obtained on the spectral distribution of radiation in the wavelength range 0.5-1.06 μm, indicating that there is some shift in a radiation maximum in the longwave spectral region.

In accordance with the definition of albedo we adopted, we also calculated its cumulative value for the same spectral range (0.5-1.06 μm), turning out to be about 0.75 for the altitude of 63 km. The surface albedo for the different spectral ranges was in the limits 0.02-0.2. The cumulative flux calculated from instrument readings in the range of 0.5-1.06 μm at the surface was about 100 W/m^2, and the illumination was about 14,000 lux.

Results of the measurements made agreed overall with the data obtained from the Venera 8 DM, when allowance is made for the differences made in the experimental conditions.

Calculated estimates of light attenuation with altitude were obtained by employing the Schwartzchild-Schuster approximation for a two-layer model. In these calculations, the lower level ($H < 50$ km) was assumed to be purely gaseous, as scattering light in the Rayleigh manner, for the upper layer ($H > 50$ km) the optical thickness τ, the albedo of single scattering ω_0, and /20
the parameter of the scattering indicatrix Γ were varied. The solar spectrum was specified for the altitude of 63 km corresponding to the beginning of measurements. The measured albedo were specified for the planetary surface.

A good approximation of calculated curves to experimental results was obtained for these upper-layer parameters: $\tau = 20\text{-}30$; $\omega_0 = 0.999$; and $\Gamma = 0.5\text{-}0.7$.

Deviations of the calculated results from the experimental values for all instrument channels at all altitudes did not exceed 30 percent.

NEPHELOMETRIC MEASUREMENTS (PRELIMINARY RESULTS)

M. Ya. Marov, B. V. Byvshev, K. M. Manuylov, Yu. P. Baranov, I. S. Kuznetsov, V. N. Lebedev, V. Ye. Lystsov, A. V. Maksimov, G. K. Popandopulo, V. A. Razdolin, V. A. Sandimirov, and A. M. Frolov

The measurements were made at the wavelength of 0.92 μm in the 62-18 km altitude range. The main cloud layer of Venus extends from the altitude of 49 km above the planetary surface; the clouds are quite transparent; and meteorological visibility is 1-3 km. The main microstructural characteristics in the cloud layer are these: the mean particle size is 1-3 μm and the particle number concentration is 500-100 cm^{-3}. One possible model of the aerosol component in the underlying atmosphere is presented: mean particle size is 2.5 μm, the particle number concentration is 2 cm^{-3}, and the index of refraction of the particle material is 1.8-2.1.

Fig. 3 shows the measured altitude dependences of the angular scattering indicators for the 4°, 15°, 45°, and 180° nephelometer channels in the Venera 9 descent region.

Fig. 4 shows the altitude trend of the attenuation indicator $\alpha(H)$ for the Venera 9 and Venera 10 stations. /21

The means of the optical and microstructural characteristics typical of the layers are in the table:

No	H, km	Venera 9					Venera 10				
		σ, cm^{-1}	S, km	r, μm	N, cm^{-3}	τ	σ, cm^{-1}	S, km	r, μm	N, cm^{-3}	τ
I	6I(62)-57	I.3	3.0	0.8	400	6	3.9	I.0	I.5	300	20
2	57 - 5I	2.3	I.7	2.0	70	I5	4.5	0.85	2.5	I20	27
3	5I - 49	I.0	4.0	I.5	60	2	4.7	0.8	2.0	200	8
4	49 - I8	0.2	20	2.5	2	3	0.2	20	2.5	2	3

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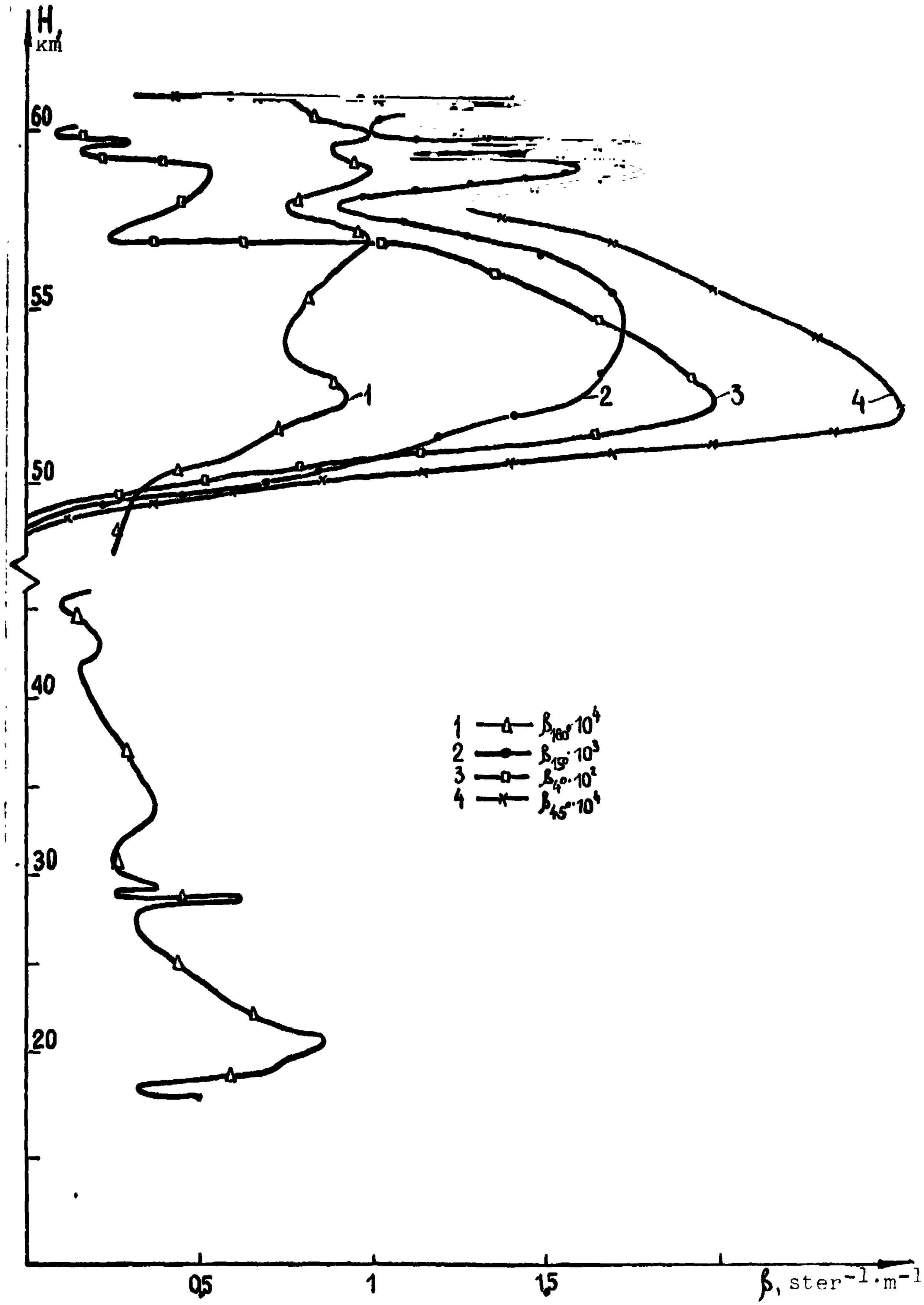

Fig. 3. Angular scattering indicators

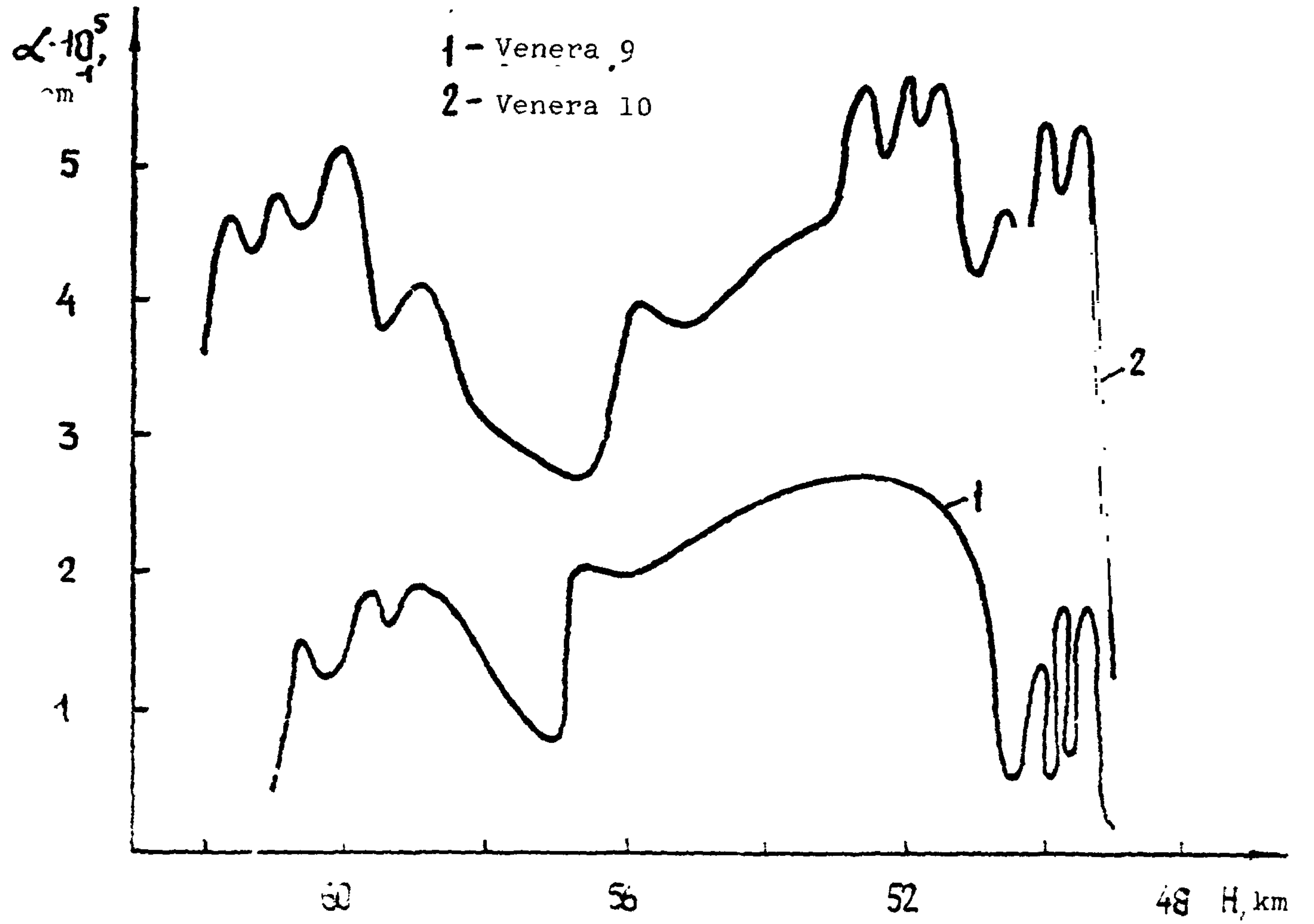

Fig. 4. Altitude trend of attenuation indicator

3. INVESTIGATIONS OF ATMOSPHERE AND CLOUD COVER FROM ONBOARD ARTIFICIAL SATELLITES

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PRELIMINARY RESULTS OF INVESTIGATING THE INFRARED SPECTRUM OF VENUS FROM ARTIFICIAL SATELLITES

V. I. Gnedykh, V. S. Zhegulev, L. V. Zasova,
V. I. Moroz, N. A. Parfent'yev, and G. V. Tomasheva

Spectrometers for the 1.6-2.8 μm range were installed on the Venera 9 and Venera 10 artificial satellites. The spectral resolution was 0.1 μm. About 20 series of measurements were made near the orbital pericenter, each of these series containing up to 150 spectrum along the path transecting the planet from the terminator to the limb. The phase angles were in the range 60-120°. Preliminary processing and interpretation of the measurements afforded these conclusions:

1. The CO_2 absorption bands about 2 μm are formed within the scattering cloud medium. The behavior of the absorption bands with change in the phase angle and the center-edge effect closely satisfies the scattering model and is not in agreement with the simple reflection model.

2. The upper limit of the cloud cover (defined as the level at which the concentration drops off by e times) is at the altitude of 65-68 km.

3. The vertical profile of the cloud layer is characterized by the altitude scale $H_a \simeq 3$-5 km.

4. The horizontal profile of the upper limit at the scales of 50-100 km and more is very smooth: variations in its altitude do not exceed 1-2 km.

5. The brightness in the continuous spectrum in the 2.2-2.4 μm region, in absolute magnitude and in terms of angular dependences, can be attributed to the model of a semi-infinite atmosphere at $a \simeq 0.98$ and $g \simeq 0.7$.

PHOTOMETRIC AND POLARIMETRIC MEASUREMENTS FROM ARTIFICIAL VENUS SATELLITES /25

L. V. Ksanfomaliti, O. F. Ganpantserova, V. P. Davydov, V. G. Zolotukhin, Ye. F. Kirillov, G. N. Krasovskiy, V. M. Filimonova, and N. G. Khavenson

The experiment's goal was studying laws of light scattering in the upper layer of Venusian clouds and, in part, in the atmospheric layer above the clouds. Measurement of the degree of light polarization in the selected phase angles allows us to find the Rayleigh scattering of light, to estimate the dispersion of cloud-layer particle sizes, and when there is a long enough series of phase angles in which the measurements were made, to determine the index of refraction of the scattering medium. Measuring the contrasts in the 3300-8000 Å range was a separate problem.

The experiment was conducted with three photometers placed aboard each spacecraft. Preliminary analysis of the data showed the following. Contrasts in the ultraviolet range reached 16-20 percent. At phase angles of 86°, the contrasts in the infrared rays did not exceed 4-6 percent. Unexpectedly large contrasts to 5-7 percent and higher were recorded on 31 October 1975 at the wavelength of 7000 Å at phase angles of 59°.

The results of ultraviolet photometric measurements allow us to state that above the surface of the main cloud layer there is a finely dispersed inhomogeneous medium with an approximate thickness of 8 km having scattering properties that are close to Rayleigh properties. Comparison of experimental data with calculated data gives a satisfactory agreement for the optical thickness of the scattering medium of 0.6-0.9. Beneath this medium is the main cloud layer of Venus with considerable absorption in ultraviolet rays. It was shown that dark contrasty /26 details can be considered as breaks or reduction in optical thickness in the upper scattering layer, which explains the nature of the ultraviolet images of Venus. The upper limit to the scattering layer is at the altitude of about 76 km above the planetary surface.

Considerable changes in polarization were observed in ultraviolet rays of a factor of three to four times along the path. There were considerable local inhomogeneities. The maximum polarization at the limb and at the terminator reached 4.5 percent, and the mean polarization was 1.5-2 percent at phase angles of 86°. These values can be interpreted as a considerable contribution of Rayleigh scattering, from 0.035 to 0.065 and relating to levels where the pressure is 40-110 mb (Fig. 5).

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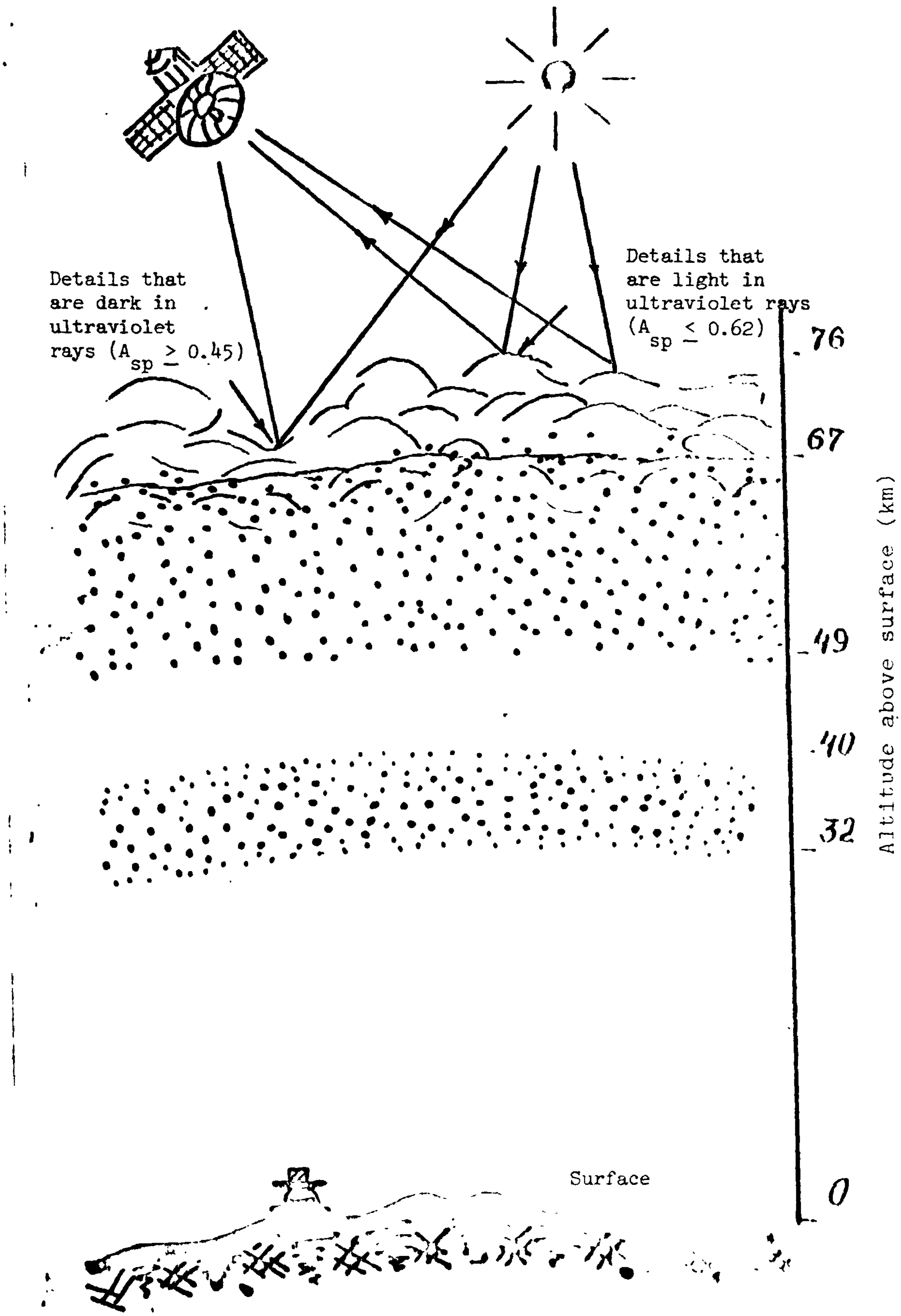

Fig. 5. Scheme of Venusian cloud cover

MEASUREMENT OF THERMAL RADIATION OF PLANET FROM ARTIFICIAL VENUS SATELLITES

L. V. Ksanfomaliti, Ye. V. Dedova, L. F. Obukhova, V. M. Pokras, A. I. Rutkovskiy, I. V. Temnaya, and G. F. Filippov

Artificial Venus satellites afforded a detailed study of the thermal radiation of the planet, its anomalies, diurnal and latitudinal trends, and association with details observed in the ultraviolet rays.

To perform these functions, aboard the artificial satellites were installed infrared radiometers, recording the thermal emission of the planet in the 8-13 and 18-28 μm ranges, along with coaxial photometers in the 3500 Å range.

The thermal IR radiation received came from the upper part of the planetary cloud layer. This layer is a thin fog, evidently made up of sulfuric acid droplets. The droplets had a diameter of about 2 μm and, at the altitude of the emitting layer, were /28
contained in the amount of 50-200 cm^{-3}; their concentration relative to CO_2 was $3 \cdot 10^{-5}$. From the data of this study and from the model of the Venusian atmosphere, the altitude of the layer from which the emission came was 63-67 km. The pressure at these altitudes is 50-130 mb.

The very first results showed that the mean brightness temperatures of the emitting layer were 233-234° K on the day side, with a strange rise in temperatures in the evening zone. An attempt was made to explain this effect by two different laws of "darkening toward the edge."

Further investigations confirmed this assumption, but showed that it is not sufficient. It was found that the night temperatures on Venus (we are speaking about the upper part of the cloud layer) is somewhat higher than the day temperatures. The difference is stable, and in the period of our measurements was 10-11° (the night temperatures are about 244° K). Thus, it was shown that thermal asymmetry of the planet was observed. The probable cause is the periods of strong convective currents in the day zone sweeping away part of the emitting material into the zone above the clouds, at an altitude of up to 3-4 km. This produces an emitting field with considerable inhomogeneities. It was shown that the "night regime" (higher temperatures) encompasses considerably more than half the planet. There are wide transitional zones in the thermal emission of the day side (Fig. 6).

These data allow us appreciably to refine the radiometric albedo of Venus, which is about 0.79.

From the results of measurements, the thickness of the layer of the corresponding optical thickness $\tau = 1$ is 4.5-5 km.

Besides the stable global asymmetry, there are a series of finer inhomogeneities, probably associated with the dynamics of planetary atmosphere.

An interesting fact was the coincidence of day temperatures with the point of phase transition of the sulfuric acid curve at a concentration of about 70 percent. This indirectly allows us to estimate the water vapor content at an altitude of 63-67 km. It must be $0.9 \cdot 10^{-4}$ with respect to carbon dioxide.

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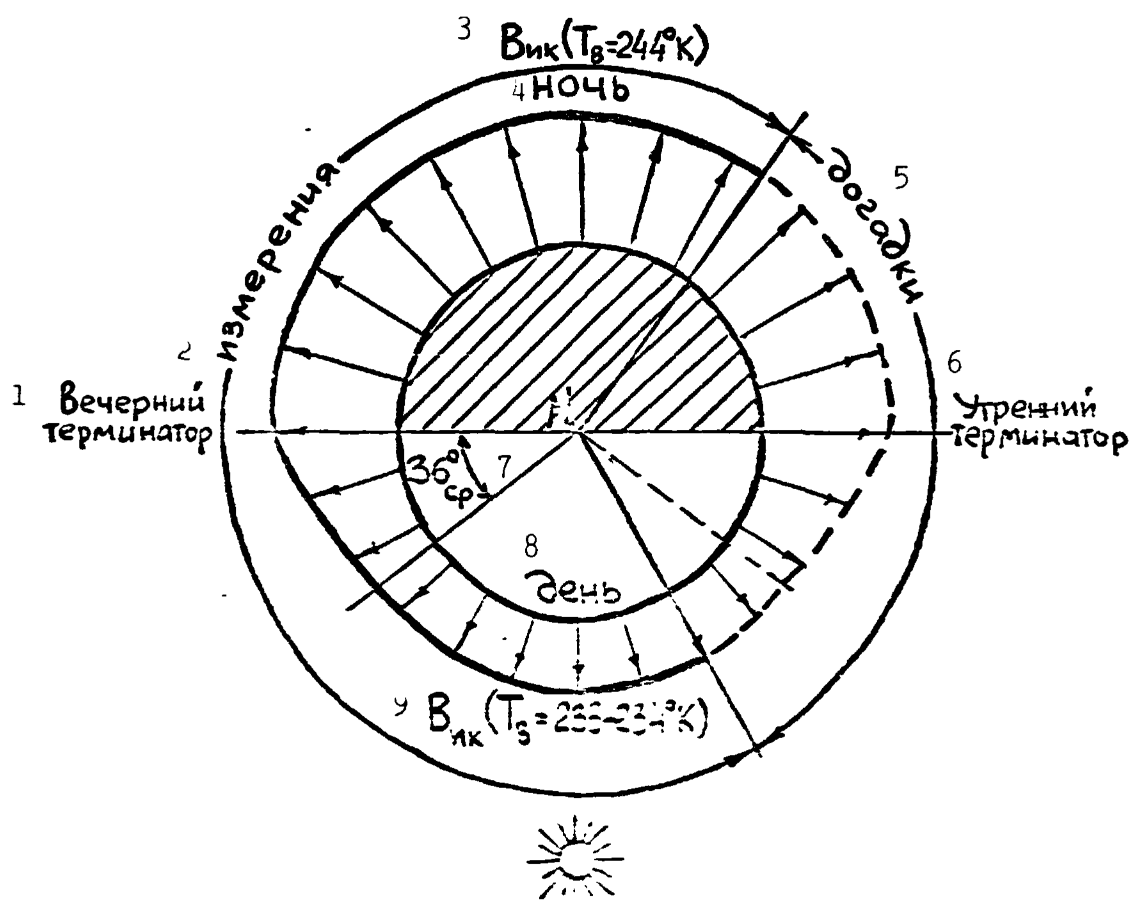

Fig. 6. Thermal asymmetry of Venus
Key:
1. Evening terminator
2. Measurements
3. $V_{infrared}$ (T_V = 244° K)
4. Night
5. Unknown
6. Morning terminator
7. $36°_{av}$
8. Day
9. $V_{infrared}$ (T_V = 233-234° K)

ATMOSPHERE OF VENUS FROM RADIO OCCULTATION DATA /30

M. A. Kolosov, O. I. Yakovlev, A. I. Yefimov,
T. S. Timofeyeva, G. D. Yakovleva, Ye. V. Chub,
V. F. Tikhonov, and V. K. Shtrykov

Forty-four radio occultations were made of the Venusian atmosphere in four regions on the night and day sides of the planet with the Venera 9 and Venera 10 artificial satellites. Altitude dependences of density, pressure, and temperature were obtained in the 40-90 km range. At the altitudes of 56-64 km, permanent stratal formations were recorded. The electron concentration was found as functions of altitude in the range H = 100-330 km for different solar zenith angles. In the 40-50 km altitude range there was good agreement with data obtained earlier from descent modules (Figs. 7 and 8).

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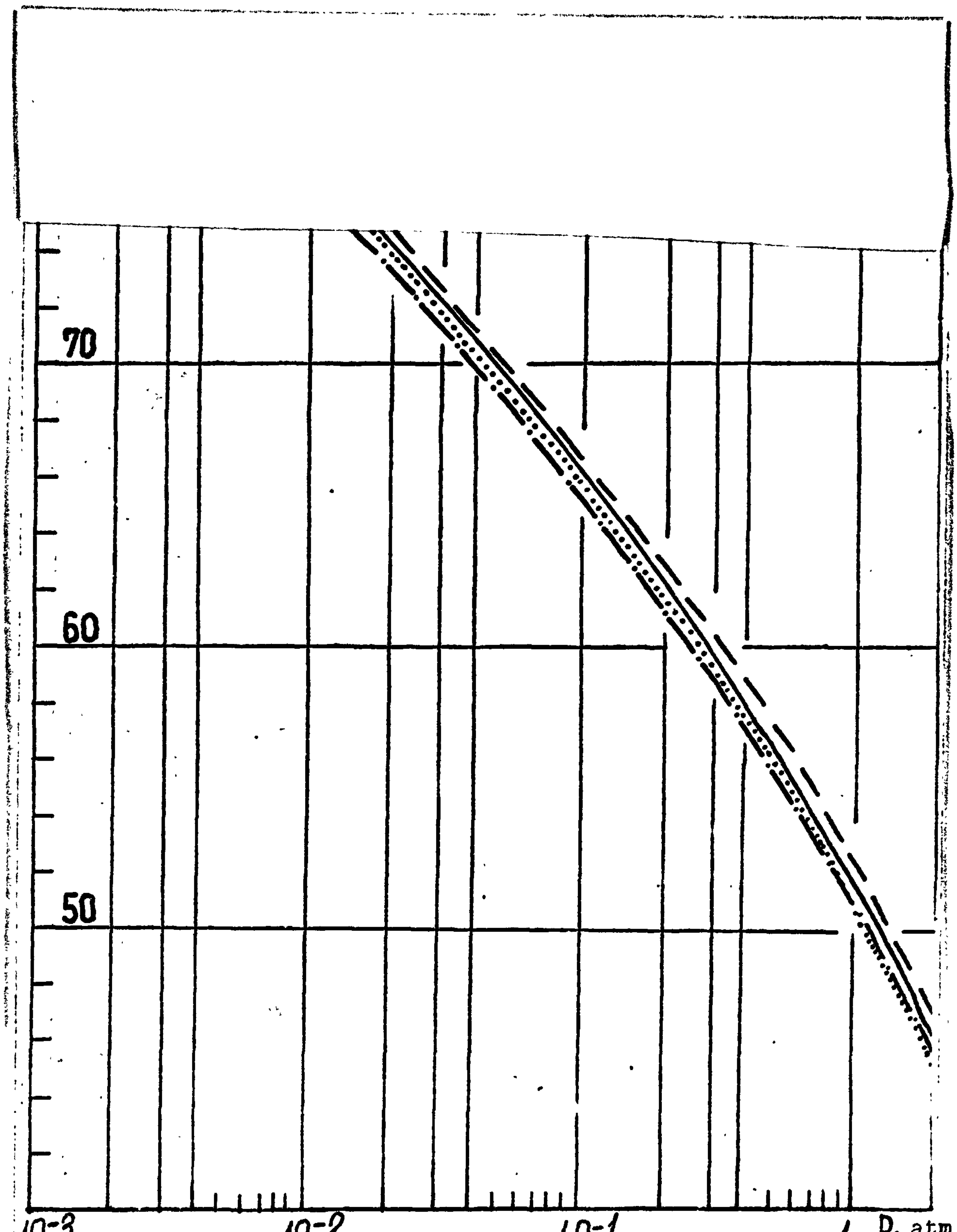

Fig. 7. Dependence of pressure on altitude from results of four radio occultations

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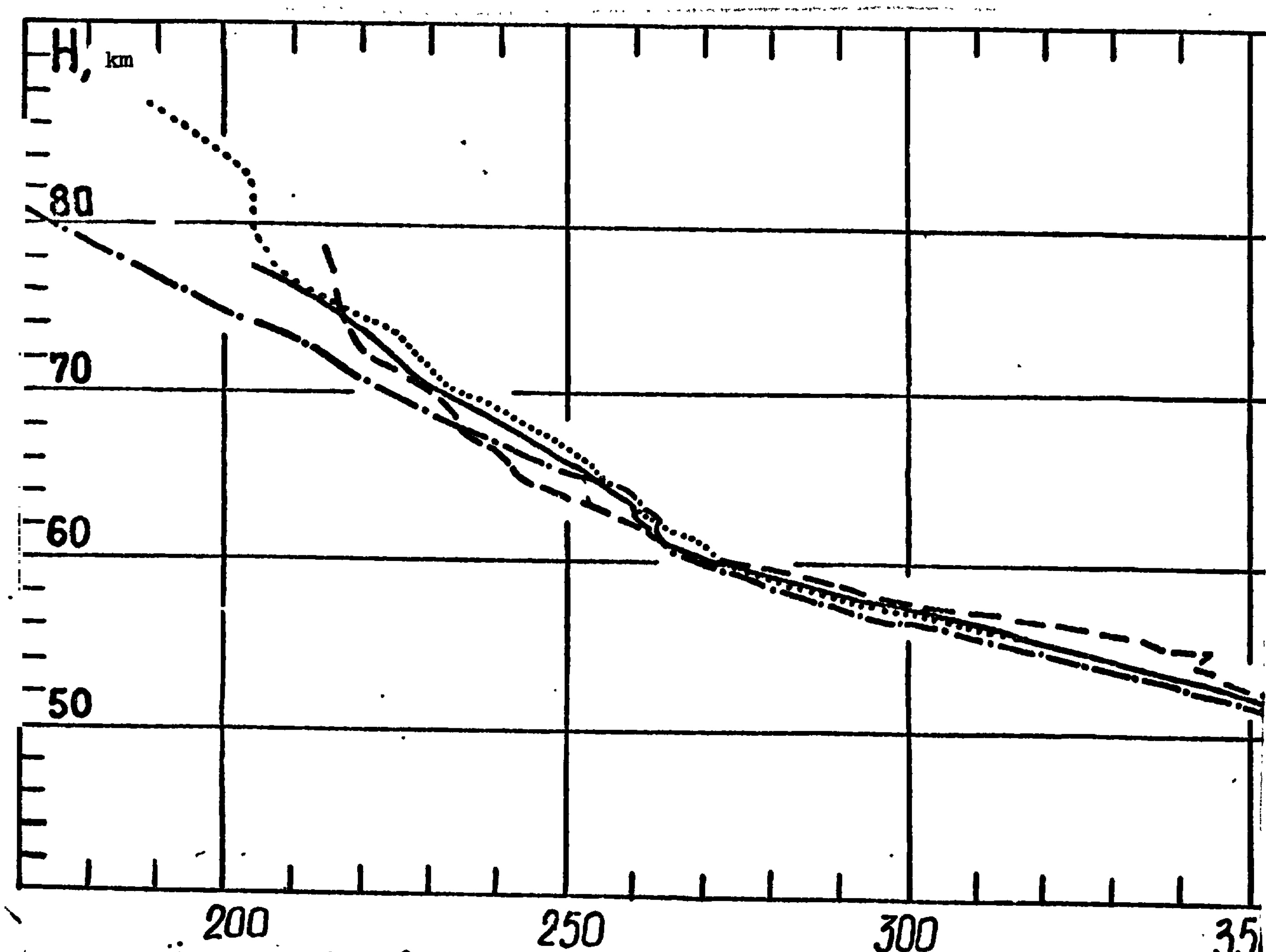

Fig. 8. Dependence of temperature on altitude above the Venusian

1-2. Venera 9
3-4. Venera 10

INVESTIGATION OF SCATTERED L_α RADIATION IN THE VICINITY OF VENUS

A. I. Dzyubenko, Zh.-L. Berto, Zh. Blamon,
V. G. Kurt, T. A. Mizyakina, Ye. N. Mironova,
N. N. Romanova, and A. S. Smirnov

Results of measuring profile and intensity of scattered L_α-radiation in the vicinity of Venus, obtained with photometers installed on the Venera 9 and Venera 10 artificial satellites, are presented. The measurements of the half-width of the profile of scattered L_α radiation were made with absorbing cells filled /33 with hydrogen and deuterium. When the incandescent filaments were energized, H_2 and D_2 molecules are partially dissociated, leading to radiation being absorbed in a band with width 0.05 Å with its center at λ_0 = 1215.7 and 1215.4 Å.

The measurements were made near the orbital pericenter in sessions lasting 80 minutes, extending to the removal of the line of sight by 2° from the planetary center. The maximum intensity near the illuminated Venusian limb was 24 kR (Fig. 9).

Distribution of the intensity beyond the planetary limb was compared with the theoretical calculation, in which the density of atomic hydrogen was given by the Chamberlain model, determined by three parameters: the height of the critical level h_c, density, and temperature at this level (n_c and T_∞). The best coincidence when measuring intensities from 450 R to 10 kR was reached when h_c = 275 km, T_∞ = 450 $\pm$ 50° K, and $n_c = 10^5$ cm^{-3} in the model of an optically thin layer. Measuring the ratio of the signal when the hydrogen cell incandescent filaments were energized and deenergized made it possible to independently estimate T_∞ = 400° $\pm$ 100° K.

The measurement of the intensity when the deuterium cell was switched on and off permitted determining the upper limit of the atomic deuterium content D/H, which does not exceed several percent.

Readings of the side-scanning detector measuring L_α radiation scattered in the hydrogen cell made it possible to discriminate radiation scattered by atomic oxygen in the Venusian atmosphere in the triplet lines OI λ 1302, 04, and 05 Å.

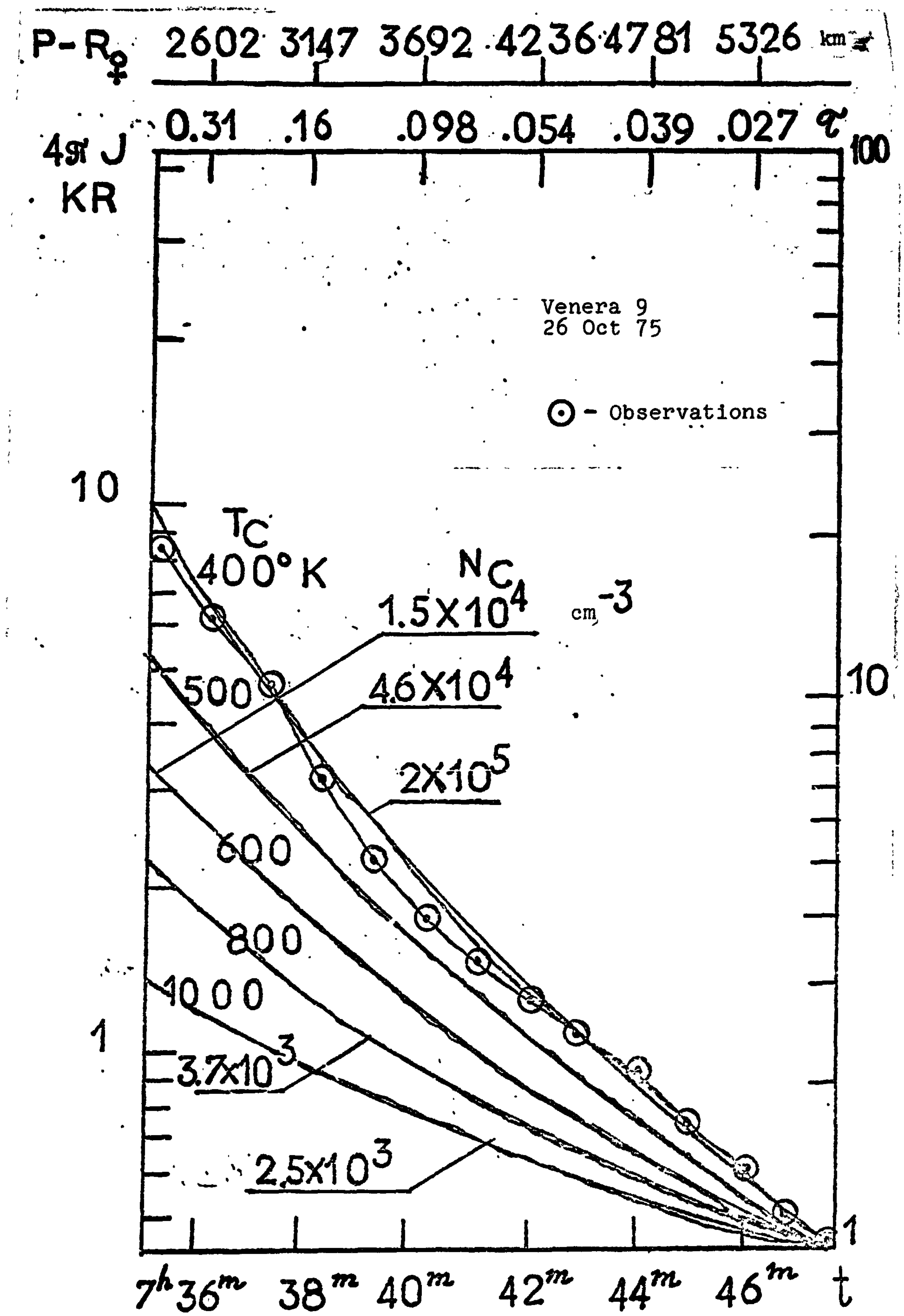

Fig. 9. Dependence of intensity of L_α radiation on time

SPECTROSCOPY OF THE VENUSIAN NIGHT SKY GLOW /35

V. A. Krasnopol'skiy, A. A. Krys'ko, and V. N. Rogachev

Identical spectrometers for absorbing the atmospheric glow and having the following characteristics were installed aboard the Venera 9 and Venera 10 artificial satellites: spectral region 3000-8000 Å, spectral resolution 20 Å, field of view 12', threshold sensitivity 30 Rayleighs, dynamic range $3 \cdot 10^4$, and spectral recording time 2.5 sec. Night glow spectra were obtained: they contain upwards of ten emissions belonging to one system of molecular bands. The intensity of the system glow was about 100 kilo-rayleighs at the planetary limb. The glow was concentrated in a layer 10-15 km thick at an altitude of about 95 km. The diurnal trend of the glow was characterized by the zenithal intensity of 4 kilo-rayleighs at an hour angle of t = 310°, by a rise to 7 kilo-rayleighs by midnight when t = 345°, and by a subsequent decrease down to 1.5 kilo-rayleighs when t = 65°. One of the glow spectra measured is in Fig. 10. Here is also shown instrumental sensitivity. This spectrum has the closest similarity to the beryllium oxide spectrum. However, the differences in the spectra -- absence of BeO bands in the twilight Venusian glow observed by the same instruments, and some aeronomic arguments, compel this identity to be rejected. Thus, the Venusian glow spectrum does not have an analog among the earlier investigated spectra and is a new band system. To identify it, 25 molecules with a vibrational frequency close to that observed (1400 cm^{-1}) was selected. By an excitation process there had to be a chemical reaction in which the energy yield exceeds 3.5 eV, the lifetime of the initial components is more than 10^5 sec, and the rate is not less than 10^3 $cm^{-3} \cdot sec^{-1}$. Of /36 all the compounds, only CO_2 molecules excited in the process

$$O + O + CO_2 \rightarrow O_2 + CO_2^*$$

satisfy these conditions. Evidently, the glow is caused by the intercombinational transition $^3B_2 \rightarrow {}^1\Sigma_g^+$. Theoretical calculations give the energy of the vertical excitation $^3B_2$ -- -- the state of 7.35 eV and the energy of the potential curve minimum of about 4 eV, which does not contradict the proposed identification. The possible explanation of the absence of analogous glow in the Martian atmosphere observed by us on the Mars 5 satellite consists in quenching of the $^3B_2$ state by molecular oxygen, and also possibly by argon. Estimates are given of the excitation constants $\alpha \approx 2 \cdot 10^{-2}$ (the probability of excitation in the above-presented process) and the quenching constants $K_{O_2} \approx 10^{-10}$, $K_O \approx 10^{-11}$, and $K_{CO_2} \approx 3 \cdot 10^{-16}$. Glow data can be used in analyzing the altitude dependence and the diurnal trend of the atomic oxygen concentrations. A qualitative explanation of the diurnal trend lies in the fact that after the setting of the Sun processes of catalytic recombination of atomic oxygen with the participation of active hydrogen forms (H, OH, HO_2, and H_2O_2) slow down, and when this happens, there must be a shift in the concentration maximum downward, leading to stronger glow. The subsequent reduction in glow is caused by a decrease in the concentration of atomic oxygen and has a time constant of about 10^5 sec (Fig. 10).

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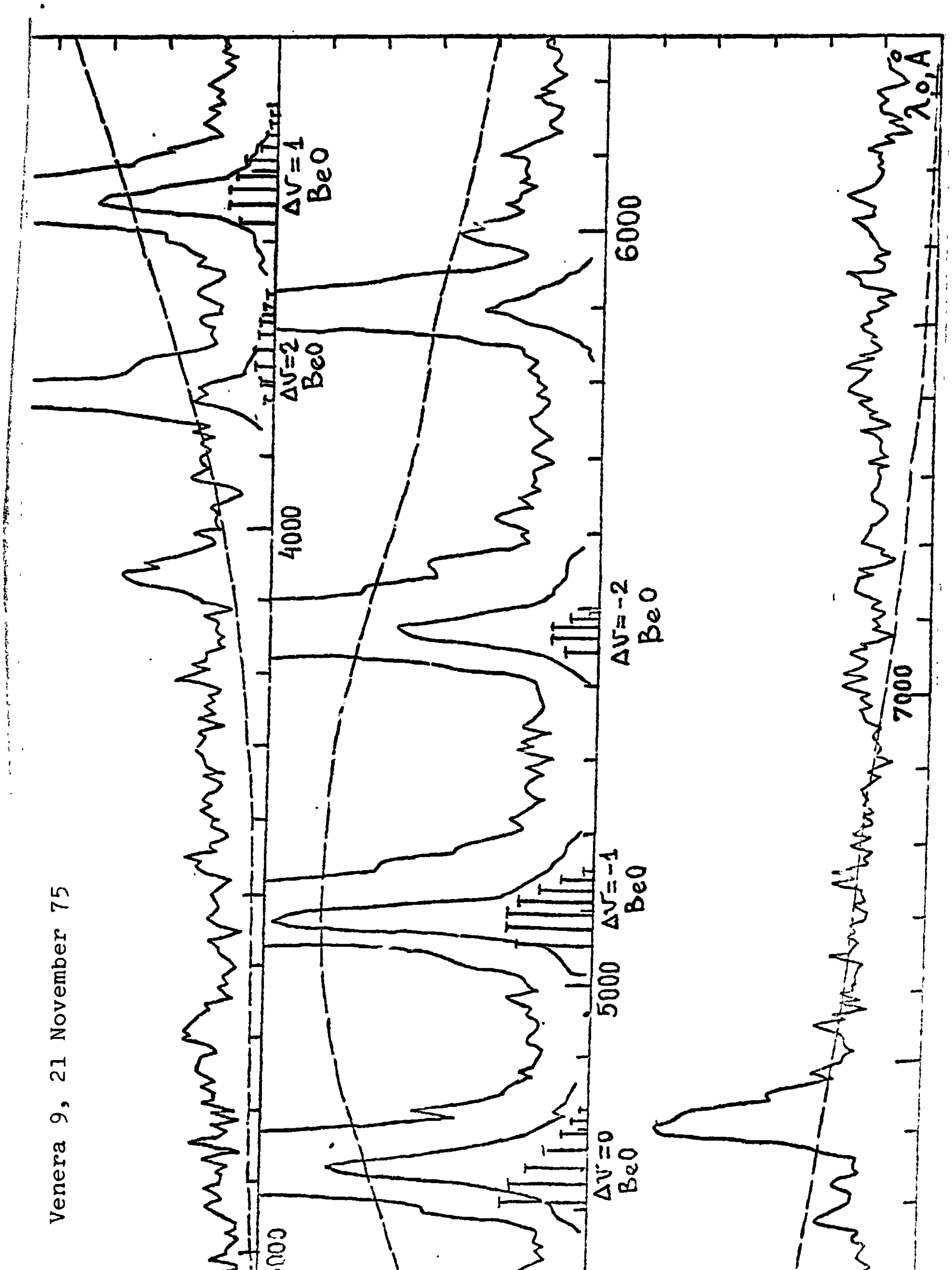

Fig. 10. Spectrum of Venusian night sky glow

4. INVESTIGATIONS OF IONOSPHERE, PLASMA, AND MAGNETIC FIELD FROM ONBOARD ARTIFICIAL SATELLITES /38

NIGHT IONOSPHERE OF VENUS FROM RESULTS OF TWO-FREQUENCY RADIO OCCULTATION

Yu. N. Aleksandrov, M. B. Vasil'yev, A. S. Vyshlov, G. G. Dolbezhayev, V. M. Dubrovin, A. L. Zaytsev, M. A. Kolosov, G. M. Petrov, N. A. Savich, V. A. Samovol, L. N. Samoznayev, A. I. Sidorenko, A. F. Khasyanov, and D. Ya. Shtern

To study the mechanism of plasma formation in the upper Venusian atmosphere, it is important to get systematic and reliable information on the altitude distribution of the electron concentration and its changes with time. This kind of data was obtained by multiple two-frequency radio occultation of the Venusian atmosphere during the flight of the Venera 9 and Venera 10 artificial satellites. The satellite orbits were such that when they passed behind Venus, there was radio occultation of the night ionosphere of the planet. Altogether, in the period from 24 Nov 75 to 7 Dec 75, there were 19 sessions of two-frequency radio occultation of the Venusian night ionosphere. The zenith angle of the Sun, $Z_{\odot}$, at the point of radio beam tangency to the planetary surface, varied from 129 to 166° in these sessions. Two well-defined maxima were observed in the 13 profiles. The values of the electron concentration in the upper maximum are in the range $3 \cdot 10^3$ to $8.8 \cdot 10^3$ cm^{-3}, and its altitude position changed from 134 to 144 km. The lower maximum was shifted relative to the upper maximum by 17-24 km and had a concentration up to $2 \cdot 10^3$ cm^{-3} (the 2 Nov 75 profile). In four cases, a single maximum with a concentration from $1.6 \cdot 10^4$ cm^{-3} (28 Nov 75 session) to $5 \cdot 10^3$ cm^{-3} (23 Nov 75 session) was observed We should take particular note of the 4 Nov 75 profile (see Fig. 11). In this profile the upper maximum differs strongly by the fact that given the high concentration, /39 its thickness is extremely small and is only 4-6 km at the level of $5 \cdot 10^3$ cm^{-3}. The profile obtained on 5 Nov 75 differs from the others by the presence of several maxima reaching values of $7 \cdot 10^3$ cm^{-3} and the total of only several kilometers. Similar thin layers are suggestive of sporatic formations typical of the E_S region of the Earth's ionosphere.

An important feature of all Venusian night ionosphere profiles is its slight extent, which is 30-50 km. The experimental data indicate a considerable variability in the parameters of the Venusian night ionosphere, reflecting substantial variations in the ionization source.

PRELIMINARY RESULTS OF TWO-FREQUENCY RADIO OCCULTATION OF THE DAY IONOSPHERE OF VENUS

Yu. N. Aleksandrov, M. B. Vasil'yev, A. S. Byshlov, V. M. Dubrovin, A. L. Zaytsev, M. A. Kolosov, G. I. Makovoz, G. M. Petrov, N. A. Savich, V. A. Samovol, L. N. Samoznayev, A. I. Sidorenko, A. F. Khasyanov, and D. Ya. Shtern

Two-frequency decimeter and centimeter range transmitters for investigating the planetary surface by radio occultation were installed on the Venera 9 and Venera 10 artificial satellites. The prolonged existence of shadowing of the satellite orbits relative to Earth permitted multiple radio occultation of the Venusian ionosphere for different conditions of solar illumination. The altitude profiles of electron concentration were calculated from the data of the reduced difference of doppler frequencies in the spherical symmetry approximation, without taking into account the curvature of the radio beams, /42 by a technique analogous to the one used in investigating the ionosphere of Mars. In the figure is shown by way of example altitude profiles obtained in three sessions of two-frequency radio occultations for different zenith angles of the Sun at the point of radio beam tangency to the planetary surface $Z_{\odot}$. The 2 Nov 75 profile was recorded when the Venera 10 artificial satellite emerged from behind the planet ($Z_{\odot} = 14°$). At the principal ionization maximum, at the altitude of $H \approx 150$ km, the electron concentration was $N \approx 4.2 \cdot 10^5$ cm^{-3}. At the altitudes of $H \approx 195$ km and $H \approx 250$ km there are additional maxima with concentrations $N \approx 6.6 \cdot 10^4$ cm^{-3} and $8.4 \cdot 10^3$ cm^{-3}. At the 28 Nov 75 profile obtained during the emergence of the Venera 9 station at $Z_{\odot} = 46°$, these additional maxima were absent, and the concentration in the principal maximum was $N \approx 3.8 \cdot 10^5$ cm^{-3}. The profile of the evening ionosphere ($Z_{\odot} = 85°$) obtained on 23 Nov 75 as the Venera 9 station emerged is marked by a relatively larger extent and can be traced to the altitude of $H \approx 600$ km. The electron concentration in the principal maximum was $N \approx 1.85 \cdot 10^5$ cm^{-3}. In all profiles in the altitude range $H \approx 125$ km there is well-defined an additional ionization maximum with concentration $N \approx 10^5$ cm^{-3}, which was not observed when there was occultation by signals from the Mariner 10 station (Figs. 11 and 12).

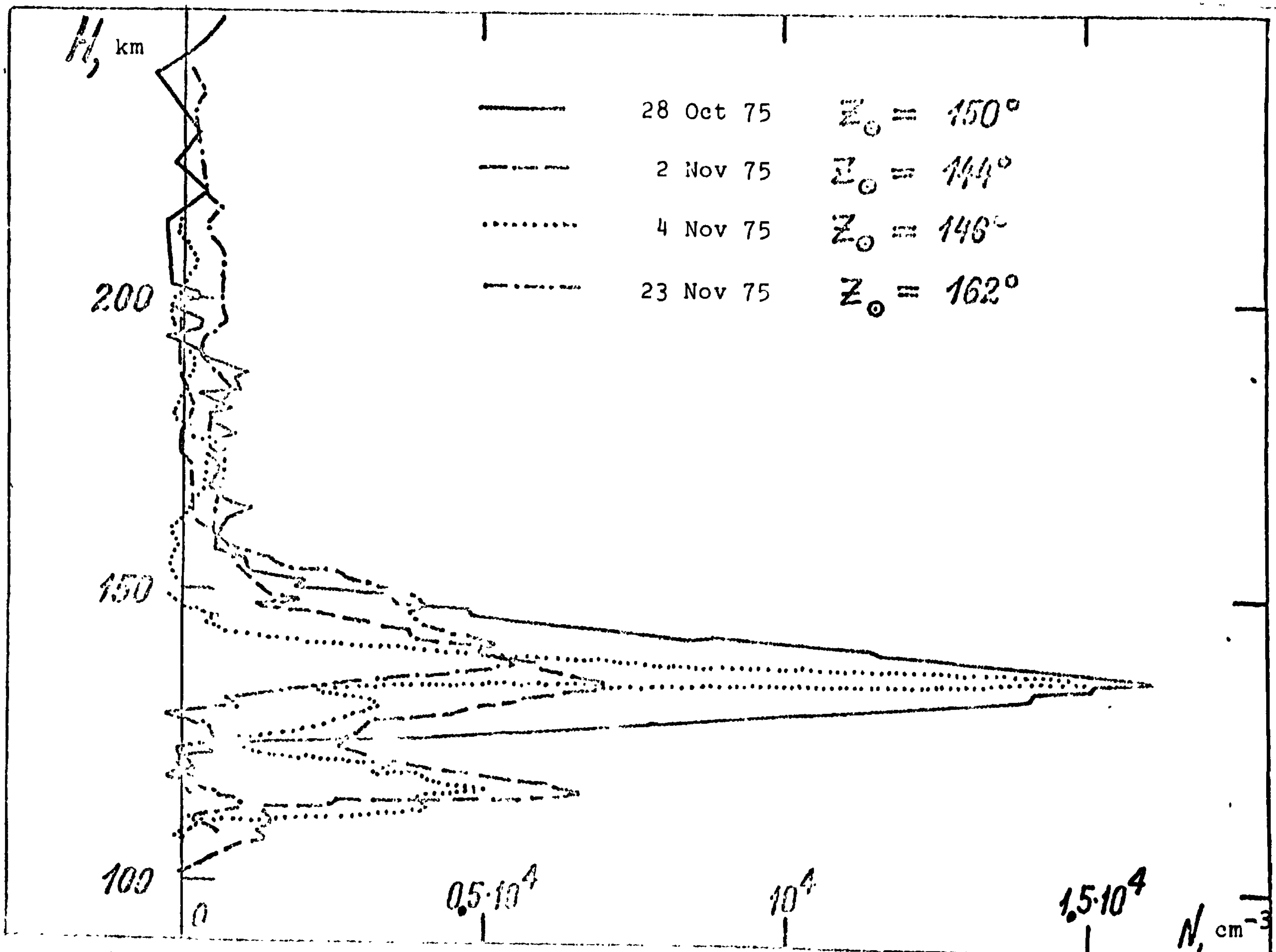

Fig. 11. Altitude profile of electron concentration (night ionosphere)

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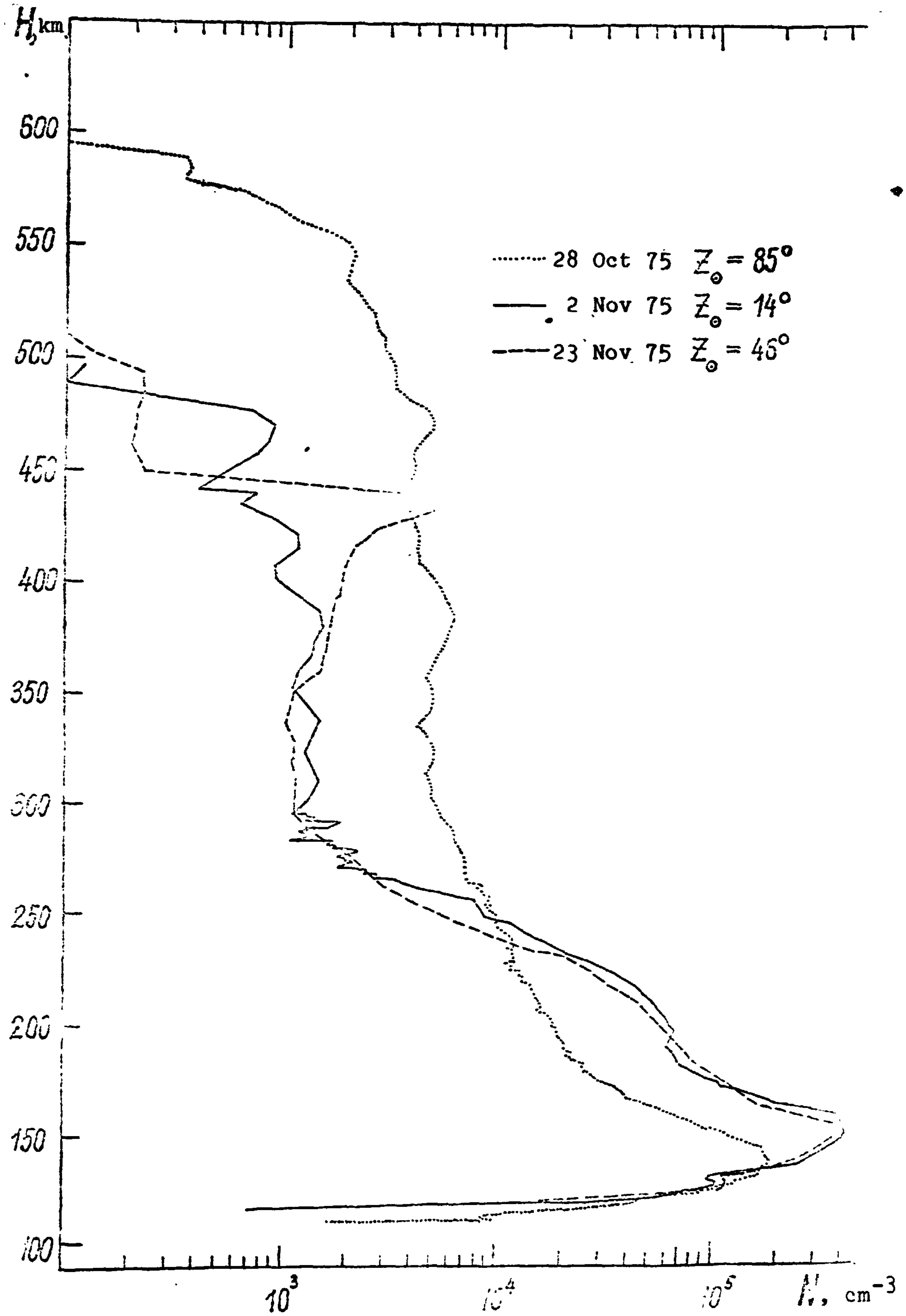

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Fig. 12. Altitude profile of electron concentration (day ionosphere)

MAGNETIC FIELDS IN THE VICINITY OF VENUS

Sh. Sh. Dolginov, Ye. G. Yeroshenko, L. N. Zhuzgov, V. A. Sharova, and B. V. Buzin

From all the interpreted magnetograms recorded on the Venera 9 and Venera 10 artificial satellites, these conclusions /43 can be drawn, dependent only to a small extent on the thus far approximate knowledge of the zero levels of the magnetometer channels:

1. Four regions with different physical properties appeared in the vicinity of Venus:

a) a quiescent solar wind

b) a shock front ($\Delta B \sim 25$-30 gammas)

c) a fluctuating field with ΔB from 5 to 30 gammas, typical of the transitional zone between the shock front and the barrier, and

d) a quieter field in the region of the penumbra and the umbra.

2. The intersections of the shock front are in agreement with theoretical models in which the planetary ionosphere is the barrier to the solar wind. Available data thus far do not permit distinguishing the models of "ionopause" and "magnetic barrier."

3. The scalar value of the field in the penumbra region exceeds the scalar value of the field in the solar wind by 5 gammas. This excess of the field can be associated with the nature of flow past Venus: an ion deficiency in the penumbra region is compensated by an excess magnetic field. The field gradient in the "penumbra" region is associated with the plasma pressure gradient at the "penumbra" boundary. In this respect, the nature of the field in the "penumbra" region can be analogous to the nature of the field on the night side of the Moon. The difference is determined by the effect of the adjoining transitional zone with the fluctuating field bounded by the "penumbra" and by the shock front (in the case of Venus).

4. The signs of the field in the region of the penumbra in the interpreted magnetogram sometimes coincide with the sign of the field in the solar wind (which is established from

readings of the second satellite), and sometimes fail to coincide. In the latter case, it was possible to detect short-term changes in the sign of the field in the solar wind with a lead time of several hours (2-5 hours). The effects of field inversion in the penumbra region had been little studied due to a limited number of interpreted paired sessions. Possibly, their observa- /44 tion will furnish data on the effects of conductivity of the "barrier" and serve as the main criterion in estimating the upper limit of the possible intrinsic magnetic field of Venus.

5. Starting from the similarity of the topology of the magnetic fields of Earth, Jupiter, Mars, and Mercury, and the fact that all the fields of these planets numerically agree in the model of the precessional dynamo showed that the planet Venus can have a field with H < 11 gammas. Revision of the limiting field is possible when there is a revision in the dynamic compression of the planet, the angle the axis of rotation makes with the orbital plane, and the determination of the planetary moment of inertia.

6. Features of the field on the night side of the planet Venus in the "penumbra" region confirms the difference from the situation in the neighborhood of Mars and once again corroborates the statement that flow past Mars by the solar wind is determined above all by the presence of an intrinsic field around Mars (Fig. 13).

TABLE

Comparison of field intensities in umbra region and in solar wind

Venera 9			Venera 10		
Date of measurement	Umbra	Solar wind	Date of measurement	Umbra	Solar wind
26 Oct 75	I0–I5 γ	I0 γ	29 Oct 75	20 γ	I5 γ
28 Oct 75	20–30 γ	I8–20 γ	31 Oct 75	I5–I7 γ	I5 γ
30 Oct 75	I6 γ	I3 γ	6 Nov 75	I3 γ	I0 γ
9 Nov 75	I5 γ	I4 γ			
11 Nov 75	I5 γ	4 γ			
25 Nov 75	I0–20 γ	7–I2 γ			

Venera 9, 25 Nov 75

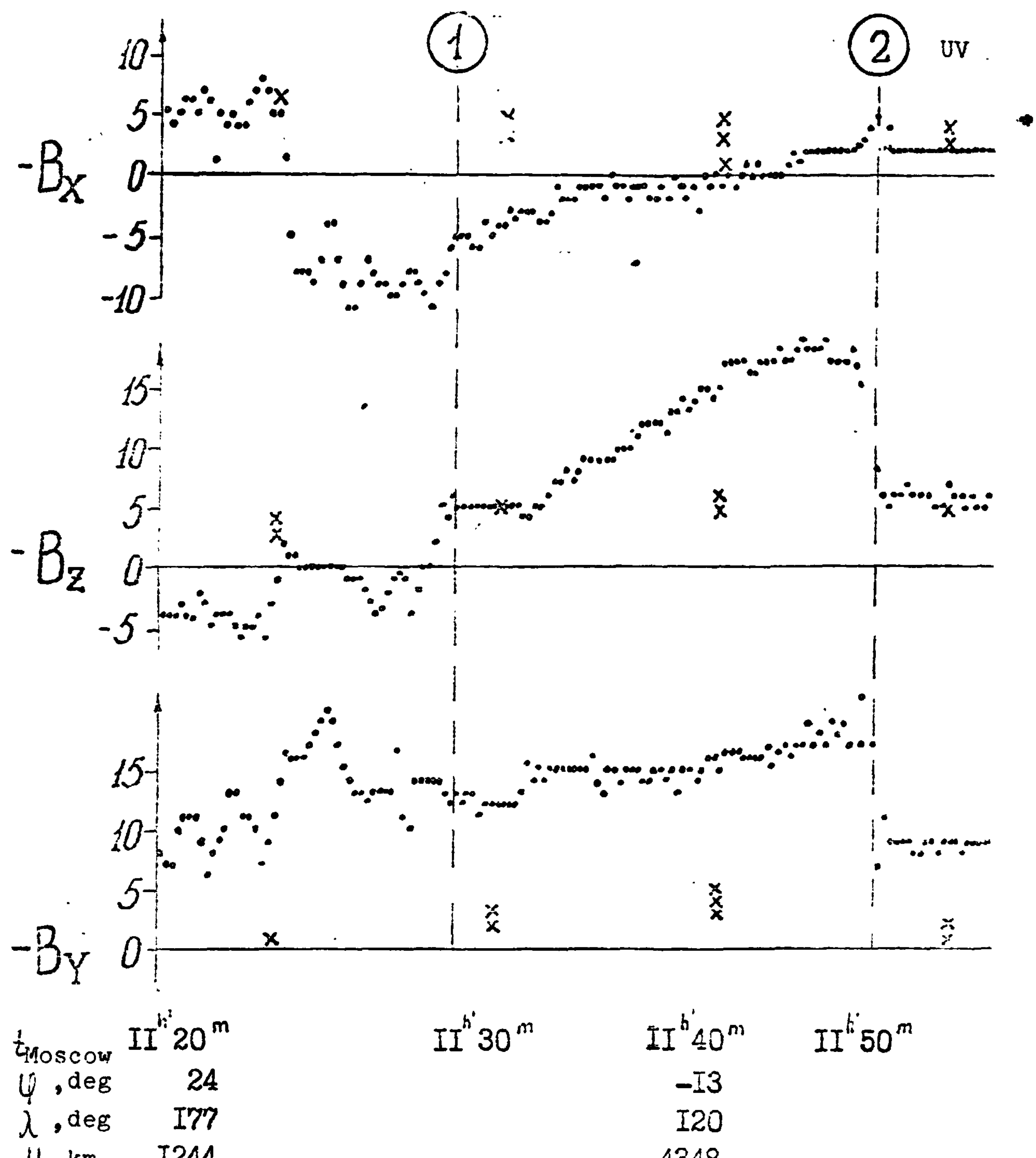

Fig. 13. Components of magnetic field in solar-ecliptical coordinates (φ, λ, H)
. - measurements on Venera 9
x - field components in solar wind (Venera 10)

PRELIMINARY RESULTS OF STUDYING THE ZONE OF SOLAR WIND-VENUS INTERACTION /46

O. L. Vaysberg, I. P. Karpinskiy, V. N. Smirnov,
B. I. Khazanov, S. A. Romanov, A. V. Bogdanov,
and B. V. Polenov

RIEP plasma spectrometers were installed onboard the Venera 9 and Venera 10 artificial satellites. The narrowly directed, electrostatic analyzers of the spectrometers, oriented in different ways, were capable of measuring the angular and energy distribution of the ion flux.

Results of analyzing measurements in a single orbit of Venera 9 and on four orbits of Venera 10 afforded these preliminary conclusions:

1. The following zones and formations were distinguished in the region of solar wind flow past Venus:

region of corpuscular shadow

region of low-energy plasma fluxes

region of rarefaction

transitional region

shock wave, and

region of precursors.

2. The instrument did not record the flux of ions with energies < 50 eV in the range of $\sim 50°$ near the Sunward direction in the region of corpuscular shadow.

3. Fluxes of ions with energies of 50-100 eV to 500 eV (at a high solar wind velocity) were observed in the region of optical shadow, before the satellite rose to an altitude of about 1000 km above the terminator (along the line of sight). The angular distribution of the ions corresponded to their /47
streaming into the region of the optical shadow from the planetary limb side. The ions had a narrow energy distribution corresponding to a temperature of 5-20 eV. The ion energy increased as the satellite emerged farther from the shadows.

4. At an altitude of about 1000 km above the terminator (along the line of sight) there appeared a flux of ions with a broad angular distribution and with an energy distribution close to the distribution in the transitional region (the rarefaction zone). This zone is distinguished from the transitional region by a lower flux value and by a narrower energy distribution, which is attributed mainly to the absence of a high-energy distribution tail. With increase in transiting of the rarefaction zone by the satellite, the flux value, the mean energy, and its scatter rose. The plasma flow velocity had a component in the direction of the cavity beyond the planet. The energy distribution of the ions showed an asymmetry expressed in a reduced flux of ions in the high-energy distribution tail when measured with an analyzer oriented closer to the center of the planet.

5. Between the region of ion fluxes with low energies and the rarefaction region there is a boundary less than 100 km thick, where abrupt variations in the ion fluxes are observed. Close to this boundary the plasma distribution function can have a two-component structure. Here there was also observed sporatic bursts of 4-6 keV ions usually not observed in other regions of the zone of solar wind-Venus interaction.

6. The recorded ion temperatures in the transitional region are about 1.5 times less than follows from the gas-dynamic model of flow past the planet.

7. The thickness of the front of the principal thermolysis of the ions at the shock wave can be about 50 km (assuming front immobility). Cases of a pulsating front or multiple scatterings /48
were observed. Ahead of the thermolysis front, upstream, there usually existed a broad (up to 10,000 km) region of precursors where severe fluctuations in particle flux density were recorded; the ion distribution function was distorted compared to the unperturbed solar wind flow.

8. The spectrum of fluctuations in the plasma flow density in the frequency range of about 0.1 Hz had a lower-frequency character in the region of precursors done in the transitional region.

9. The position of the shock wave front from our data is in agreement with the data of the preceding observations made of Venus and corresponds roughly to the gas-dynamic model of Sprighter with $H/r_0 = 0.01$.

Here the boundary between the zone of low-energy fluxes and the penumbra is in satisfactory agreement with the ionopause model for the same Hr_0.

10. The nature of the angular and energy distribution of ions in the region of low-energy fluxes and the existence of a boundary between this region and the rarefaction zone afford the assumption that the region of low-energy fluxes is an ionospheric plasma entrained by the external flow.

The rarefaction zone in the region of low-energy fluxes can evidently be viewed as an analog of the boundary layer.

11. The existence of the rarefaction zone where the plasma fluxes diminish, the velocity is directed toward the region of the cavity, and the high-energy tail of the ion distribution function is sharply reduced, shows that Venus absorbs a significant part of the solar wind ion flux. An estimate of the deficit of the plasma flux in the rarefaction zone, on the assumption that this deficit is wholly attributed to plasma losses at the barrier, corresponds to an absorption of about 40 percent of the flow in the section equal to the planetary disk in area. /49

PRELIMINARY RESULTS OF MEASURING PLASMA WITH WIDE-ANGLE INSTRUMENTS

K. I. Gringauz, V. V. Vezrukikh, T. K. Breus, M. I. Verigin, G. I. Volkov, T. Gomboshi, and A. P. Remizov

Plasma measurements were made on the Venera 9 and Venera 10 artificial satellites in October 1975. The ion component was measured on Venera 9 with a Faraday cylinder (a modulation ion trap), and the electron component was measured with a plane analyzer with a decelerating potential; only the electron component was measured on Venera 10.

Multiple measurements were made in the optical shadow of the planet, in the transitional zone between the "barrier" producing a circumplanetary shock wave, and the shock wave front, during transiting of this front and in the unperturbed solar wind.

Fig. 15 presents as an example cumulative electron and differential ion energy spectra for the circumplanetary section of the orbit of Venera 9 obtained on 1 Nov 75. The section of /51
the orbit is shown in the coordinates X, $\sqrt{Y^2 + Z^2}$ (the X axis passes through the center of the planet and is Sunward in direction).

The cumulative energy spectra of electrons corresponding to the electron concentration $n_e \sim 1\ cm^{-3}$ (less than in the transitional zone) and the temperature $T_e \sim (2-5)\cdot10^5$ ° K were regularly measured in the optical and corpuscular planetary shadow. In the same region, on an average in about 70 percent of the telemetric interrogations, the measured ion fluxes were found to be below the instrument sensitivity limits, and in about 30 percent of the cases ion fluxes were recorded that fluctuated in value, randomly distributed over the entire energy ranges to 4.1 keV (see spectra (a) in Fig. 15). On exiting from the region of corpuscular shadow (located several hundreds of kilometers above the boundary of the optical shadow), a "corpuscular penumbra" was observed in the transitional zone, and within the penumbra were observed ion fluxes (spectra (b)) slower compared to the transitional region. In the transitional zone (spectra (c) and (d)) the ion fluxes in each energy interval varied very strongly. The plasma parameters in this zone were determined from current values averaged over 10 sec in each energy range. As the satellites moved from the "corpuscular penumbra" to the shock wave front, the plasma concentration in the transitional

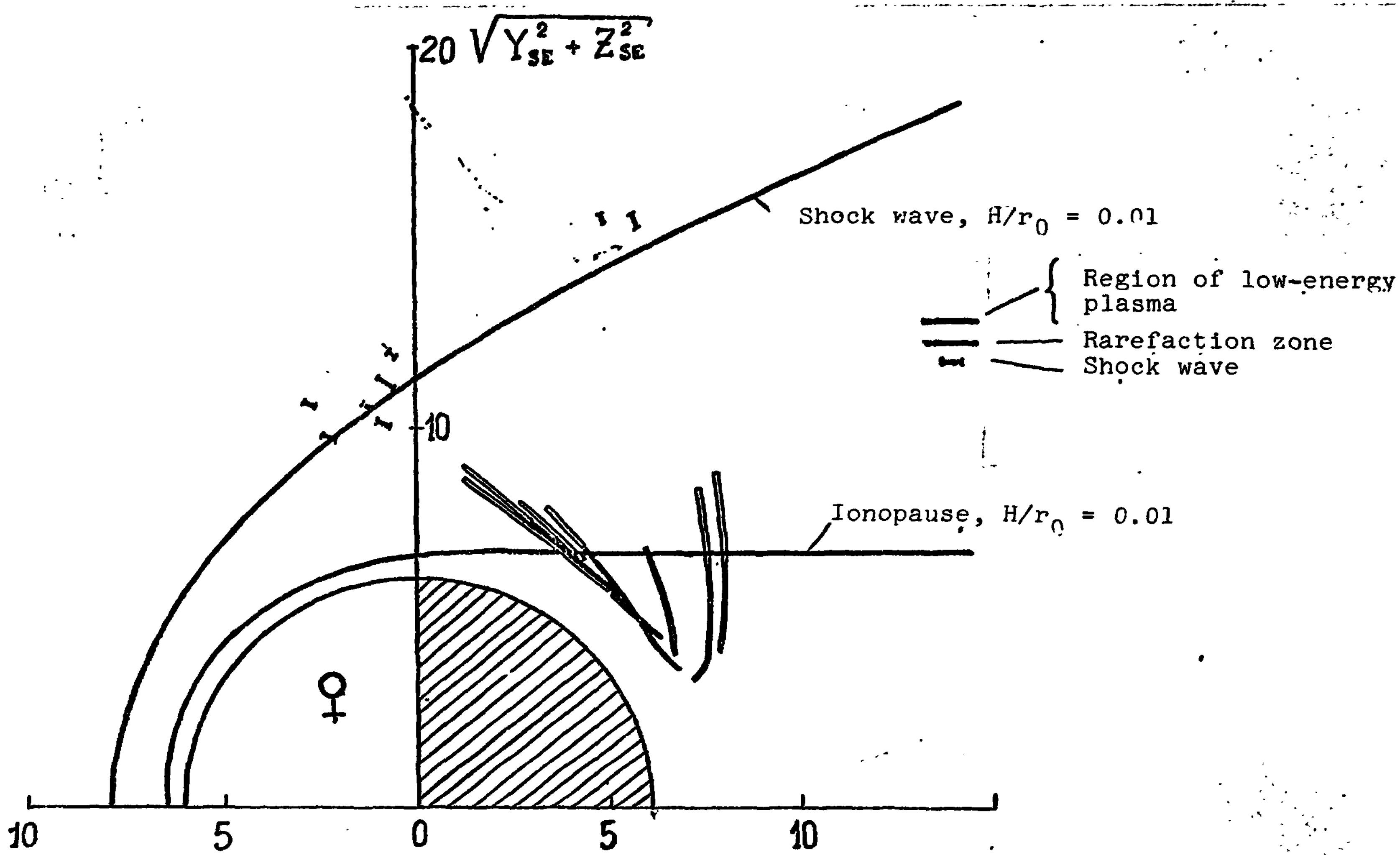

Fig. 14. Morphology of zone of solar wind-Venus interaction

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zone n rose very appreciably (by 20-50 times). In transiting the shock wave front S (spectra (e)), a jumplike reduction in n in several cases was also very appreciable (sometimes more than fourfold).

Jumps in the plasma concentration at the shock wave front this large, and the increase in n between the zone of the corpuscular shadow and the front are possibly linked to the presence of additional degrees of plasma freedom in the transitional region (vibrational) and with a corresponding reduction /52 in the adiabat index γ compared to the often-used value of 5/3. It is not precluded that the increased plasma concentration gradient in the direction from the shock wave front to the boundary of the corpuscular shadow compared to the near-Earth case are associated with a different nature of corpuscular shadow, the magnetopause in the case of the Earth, and the diffuse atmospheric boundary in the case of Venus.

In transiting (at different satellite orbits) the shock wave front, front structures differing widely from each other were observed: a very narrow front (thickness of the order of about 20 km), and a front "pulsating" over the extent of about 300 km (with considerable vibrations of the ion fluxes; an alternative explanation of the observed data can be the vibrational motion of the narrow shock wave front in the direction of the satellite orbit, at velocities exceeding the satellite velocity), a very broad front at which the transition from the charged particle spectra typical of the solar wind to spectra typical of the transitional region occurs over the orbital section having length of about 3000 km, and so on.

In the unperturbed solar wind (spectra (f)), in most cases well-defined energy spectral lines and electrons were recorded, with small fluctuations in the particle fluxes in a single energy range over 10 sec (Fig. 15).

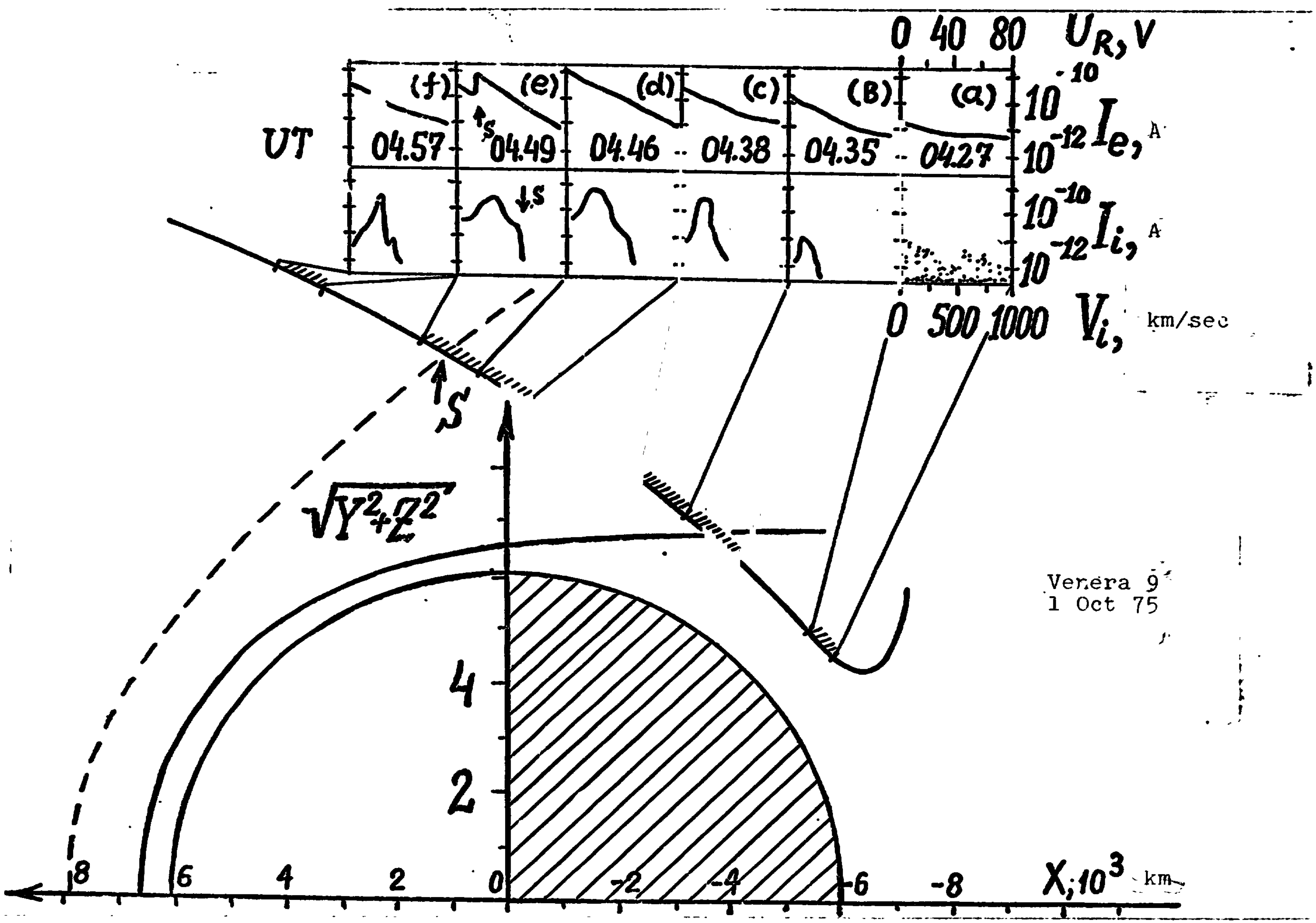

Fig. 15. Electron and ion energy spectra

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MEASUREMENT OF INTERPLANETARY BACKGROUND OF LOW-ENERGY CHARGED PARTICLES

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Investigations of low-energy charged particle fluxes were made on the Venera 9 and Venera 10 automatic interplanetary stations; a detailed measurement was made of the differential energy spectrum of protons in the energy range (0.075-5) MeV. By processing the experimental data for June 1975, instants of time with the smallest particle fluxes were found and energy spectra were constructed for them. The figure shows the results of measurements of spectra in both stations. For comparison, indicated with a solid line is the spectrum earlier in 1965 (1), and with the dashed, the spectrum measured in 1971 (2). The exponent of the power function of the spectrum in 1971 was about 3. The energy spectrum of protons in June 1975 differed from the published results, especially as to slope. It is more gradual and is described by the power function $dN/dE = 1.8 \cdot 10^2 E^{-2.3}$ protons/cm$^2 \cdot$sec$\cdot$ster$\cdot$keV.

At the time of measurement, the stations were at different distances from the Sun. So the observed small differences in the background particle fluxes at the different stations can be associated with some changes in the flows in space or with small differences in the energy thresholds.

The ratio of the proton flux to the helium nuclei in the energy range (0.5-5) MeV was 6 ± 2, and the slope of the spectrum was close to the slope of the proton spectrum (Fig. 16).

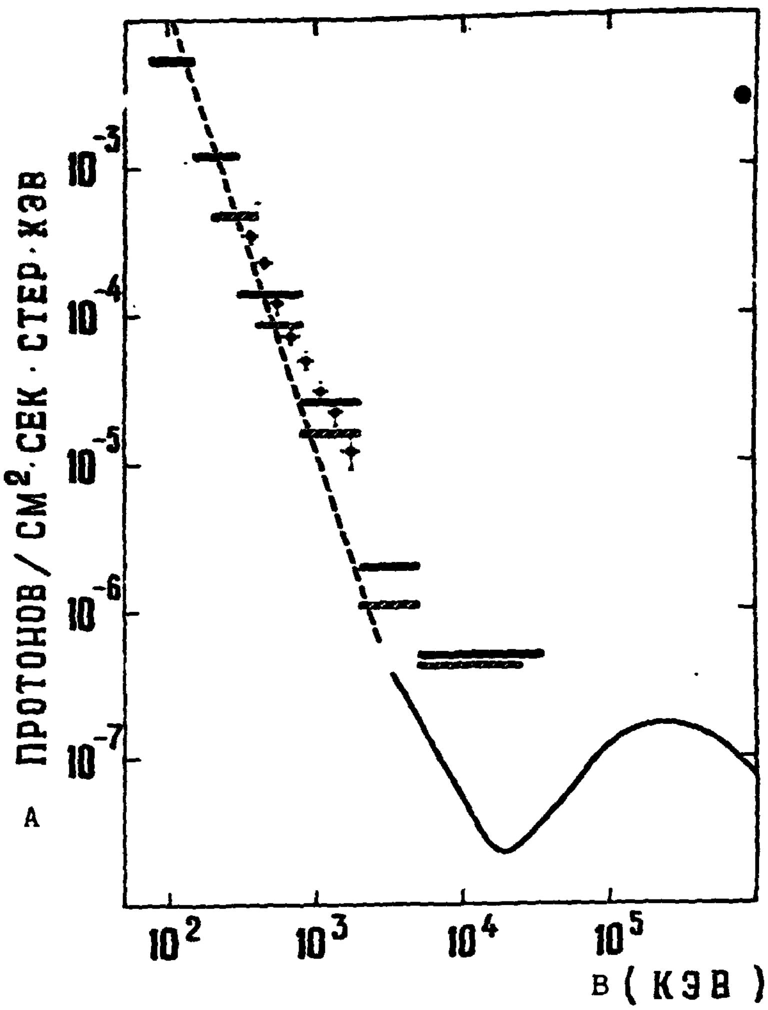

Fig. 16. Energy spectrum of proton background

▬▬ - results of measurements on Venera 9, June 1975 (I - data of analyzer normalized by means of particles in discrete energy ranges)

▭▭ - results of measurements on Venera 10, June 1975

- - - - Lin et all, 1971

____ - Fan et all, 1965

Key: A. Protons/cm^2·sec·ster·keV

B. (keV)

The following took part in preparing and readying the manuscript: Z. G. Bereznyak, M. G. Volkova, V. D. Davydov, T. P. Zvereva, and N. P. Slovokhotova. /60